МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ УКРАЇНИ

“КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ імені ІГОРЯ СІКОРСЬКОГО”

Механіко-машинобудівний інститут

Динаміки і міцності машин та опору матеріалів

"На правах рукопису" «До захисту допущено»

УДК__________ Завідувач кафедри ДММ та ОМ

__________Пискунов С. О

“___”____________2020 р.

Магістерська дисертація

на здобуття ступеня магістра

за освітньо-професійною програмою «Динаміка і міцність машин»

зі спеціальності 131 «Прикладна механіка»

на тему: «Міцність композитної конструкції шафи салону пасажирського літака»

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Рівень вищої освіти – другий (магістерський)

Спеціальність – 131 «Прикладна механіка»

Освітньо-професійна програма – «Динаміка і міцність машин»

ЗАТВЕРДЖУЮ

Завідувач кафедри

________ Сергій ПИСКУНОВ

«___»_____________2020 р.

ЗАВДАННЯ
на магістерську дисертацію студенту
Кирпа Олексій Володимирович

1. Тема дисертації «Міцність композитної конструкції шафи салону пасажирського літака», науковий керівник дисертації Оніщенко Євген Євгенович, кандидат технічних наук, доцент, затверджені наказом по університету від «___» 2020 р. № ____

2. Термін подання студентом дисертації: 10.12.2020 р.

3. Об’єкт дослідження: конструкція шафи з композитного матеріалу.

4. Предмет дослідження: створення та розрахунок моделі шафи при екстрених ситуаціях в експлуатації літака, та отримання задовільних результатів міцності.

5. Перелік завдань, які потрібно розробити:

   1) Огляд сучасного стану проблеми технології шафи з композитного матеріалу
   2) змоделювати скінченно-елементну модель у програмному комплексі Patran
   3) проаналізувати отримані результати
   4) розробка стартап–проекту.

6. Орієнтовний перелік графічного (ілюстративного) матеріалу – 6 і більше.

7. Орієнтовний перелік публікацій – 1 і більше

8. Дата видачі завдання: 01.09.2020 р.

Календарний план

№ з/п	Назва етапів виконання магістерської дисертації	Термін виконання етапів магістерської дисертації	Примітка
1	Ознайомлення з літературою	01.09.20 - 19.09.20	
2	Ознайомлення з програмним середовищем Patran/Nastran	20.09.20 – 09.10.20	
3	Розробка скінченно-елементної моделі з метою отримання значень внутрішніх зусиль	10.10.20 – 31.10.20	
4	Обробка отриманих результатів	01.11.20 – 19.11.20	
5	Стартап-проект та висновки	20.11.20 – 10.12.20	

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Науковий керівник ____________ Євген ОНІЩЕНКО

CONTENTS

Abstract

The master`s degree dissertation for the amount of work is 100 pages, 59 figures, 42 tables, and contains 5 literature.

The strength of the structure of the composite material of the cabin of the passenger plane is investigated.

The finished elemental model of a case with use of software complexes MSC Patran, MSC Nastran is constructed. The process of choosing the types of finite elements, calculation methods, cases of loads is described in detail.

The results of calculation of the stress-strain state of the cabinet and its fastening elements to the floor and ceiling of the cabin of the aircraft under loads that may occur in critical cases in the operation of the aircraft are presented. Coefficients of safety margin of all elements of a case and fastenings are defined.

It is established that all elements of the hull structure have a sufficient margin of safety, their margin of safety is in the range from 0.1 to 5. It was found that the fastening elements of the cabinet to the floor and ceiling of the cockpit need strengthening, because their margins do not exceed 0.2.

A practically important recommendation on the need to strengthen fasteners has been formulated.

Реферат

Дана магістерська дисертація за обсягом роботи складає 100 сторінок, 59 ілюстрацію, 42 таблицю та містить 5 літературних джерел.

У роботі досліджена міцність конструкції з композитного матеріалу шафи салону пасажирьского літака.

Побудована скінчено елементна модель шафи із застосуванням програмних комплексів MSC Patran, MSC Nastran. Детально описаний процес вибору типів скінчених елементів,методів розрахунку, випадків навантажень.

Наведено результати розрахунку напружено-деформованого стану шафи і елементів її кріплення до підлоги і стелі салону літака при навантаженнях, які можуть виникати при критичних випадках в експлуатації літака. Визначені коефіцієнти запасу міцності усіх елементів шафи і кріплень.

Встановлено, що усі елементи конструкції корпусу мають достатній запас міцності, їх коефіцієнти запасу міцності знаходяться в діапазоні від 0,1 до 5. Виявлено, що елементи кріплення шафи до підлоги і стелі кабіни літака потребують посилення, оскільки їх коефіцієнти запасу міцності не перевищують 0.2.

Сформульована практично важлива рекомендація щодо необхідності посилення елементів кріплення.

1. Introduction

Centerline closet - is designed to accommodate things and equipment in the cabin of a passenger plane and has the necessary items to ensure a comfortable flight of passengers. In modern aircraft to obtain weight and technological advantages, the cabinet is made of composite materials and structurally is a separate module.

Possible destruction of individual structural elements of the cabinet or its fastening elements to the power set of the fuselage in critical operational situations can lead to injury to passengers and even death. Therefore, the topic of research aimed at ensuring the strength in the design of the composite structure of the cabin of a passenger plane is relevant.

1.1. The purpose and objectives of the study

The purpose of the study - to obtain positive values of the margin of safety of the structural elements of the cabinet of composite material in possible critical situations in the operation of the aircraft.

The aim of the study is to create an analytical model of the cabinet of composite materials for static analysis.

1.2. Practical meaning

The practical significance of this study is to obtain the results of the behavior of various components made of composite, in different design cases in operation.

1.3. Object of research and research methods

The object of this study is a cabinet made of composite materials and aluminum elements of its attachment to the floor and ceiling of the aircraft cabin. The research method used in this work - numerical method - the finite element method.3D View and location of Closet is shown on Figure 1

Figure 1. Centerline C1 Closet Installation 3D View and Location

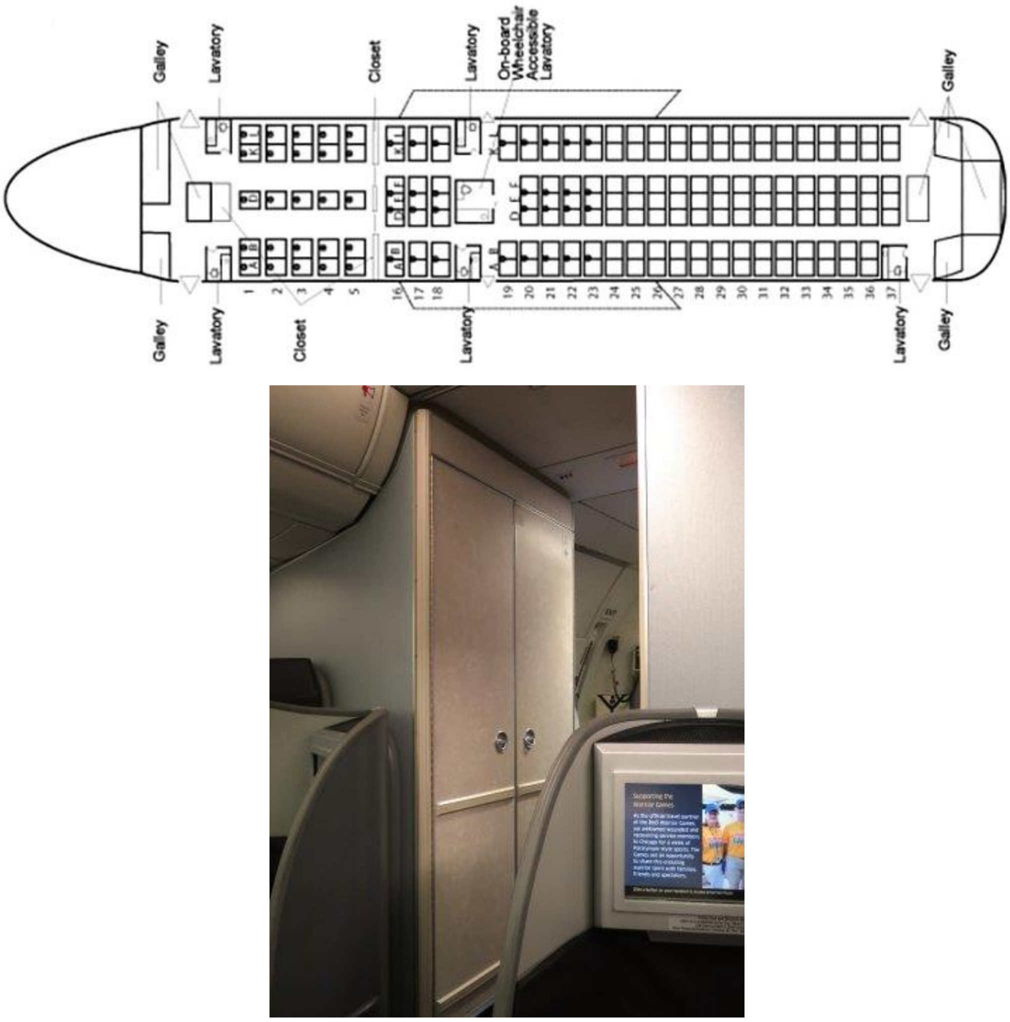


Figure 2. Centerline C1 Closet Installation   Location

2. Finite element model

2.1. Finite Element Method history

Engineering applications of finite element analysis is approximately 40 years old. Evolution of FEA is tied with the development in computer technology. With the enhancement in computer speed and storage capacity, FEA has become a very valuable engineering tool. NASA is credited for developing comprehensive FEA software in 1960's, known as NASTRAN. Rights of the software were purchased by McNeal Schwendler Corporation, who refined it and commercially marketed it under the name, MSC-NASTRAN. The first college course in FEA was offered in 1970. In the early 1970's, application of FEA was limited to large corporations, who can afford expensive mainframe computers. However, in 1980's, with the introduction of desktop computers, application of FEA became popular and indispensable engineering tool. In late 80's, almost all the major FEA vendors introduced their software that can run on a PC. In the past ten years, there were several significant development in FEA, including:

- Introduction of P- elements.
- Integration of sensitivity analysis and optimization capabilities.
- Availability of faster and cheaper desktop computers to run FEA software that previously required mainframe computers.
- Development of powerful CAD programs for modeling complex structures.
- Making software user-friendly.

2.2. How FEA works

The following steps can summarize FEA procedure that works inside software:Using the user's input, the given structure is graphically divided into small elements (sections or regions) so that each and every element's mechanical behavior can be defined by a set of differential equations. The differential equations are converted into algebraic equation, and then into matrix equations, suitable for a computer-aided solution. The element equations are combined and a global structural equation is obtained. Appropriate load and boundary conditions, supplied by the user, are incorporated in to the structural matrix. The structural matrix is solved and deflections of all the nodes are calculated. A node can be shared by several elements and the deflection at the shared node represents deflection of the sharing elements at the location of the node. Deflection at any other point in the element is calculated by interpolation of all the node points in the element. An element can have a linear or higher order interpolation function. The individual element matrix equations are assembled into a combined structure equation of the form {F}=[k]{u}. As defined earlier, {F} = Column matrix of the externally applied loads. [k] = Stiffness matrix of the structure, which is always a symmetric matrix. This matrix is analogues to an equivalent spring constant of several connected springs.

FEA solution of engineering problems, such as finding deflections and stresses in a structure, requires three steps:

- pre-process or modeling the structure;
- analysis;
- post processing [An Overview of the Finite Element Analysis]

Step1: Pre-process or modeling the structure

Using a CAD program that either comes with the FEA software or provided by another software vendor, the structure is modeled. The final FEA model consists of several elements that collectively represent the entire structure. The elements not only represent segments of the structure, they also simulate it is mechanical behavior and properties. Regions where geometry is complex (curves, notches, holes, etc.) require increased number of elements to accurately represent the shape; where as, the regions with simple geometry can be represented by coarser mesh (or fewer elements). The elements are joined at the nodes, or common points.

In the pre-processor phase, along with the geometry of the structure, the constraints, loads and mechanical properties of the structure are defined. Thus, in pre-processing, the entire structure is completely defined by the geometric model. The structure represented by nodes and elements is called “mesh”.

Step 2: Analysis

In this step, the geometry, constraints, mechanical properties and loads are applied to generate matrix equations for each element, which are then assembled to generate a global matrix equation of the structure. The form of the individual equations, as well as the structural equation is always $\{F\} = [K]\{u\}$.

The equation is then solved for deflections. Using the deflection values, strain, stress, and reactions are calculated. All the results are stored and can be used to create graphic plots and charts in the post analysis.

Step 3: Post processing

This is the last step in a finite element analysis. Results obtained in step 2 are usually in the form of raw data and difficult to interpret. In post analysis, a CAD program is utilized to manipulate the data for generating deflected shape of the structure, creating stress plots, animation, etc. A graphical representation of the results is very useful in understanding behavior of the structure.

2.3. Types of elements used in the model

The installation of CLOSET is analyzed using the finite element analysis software MSC (combination of MSC PATRAN and MSC NASTRAN). For an accurate analysis by FEM, selection of the proper elements is very important. The selected elements must represent the engineering structure as close to the original structure as possible. In this analysis, shell elements (QUAD4) are used to model the

Parts of CLOSET. MPC elements (RBE3) are used to simulate the Equipment. BUSH elements, BAR elements, MPC (RBE2) are used to simulate the joints between the Parts, such as Dog-Bone connection, Tab & Slot connection, etc.

The CLOSET has been analyzed as a stand-alone model with no load share from other models. A Finite Element Model is presented in the Figure 3.1.

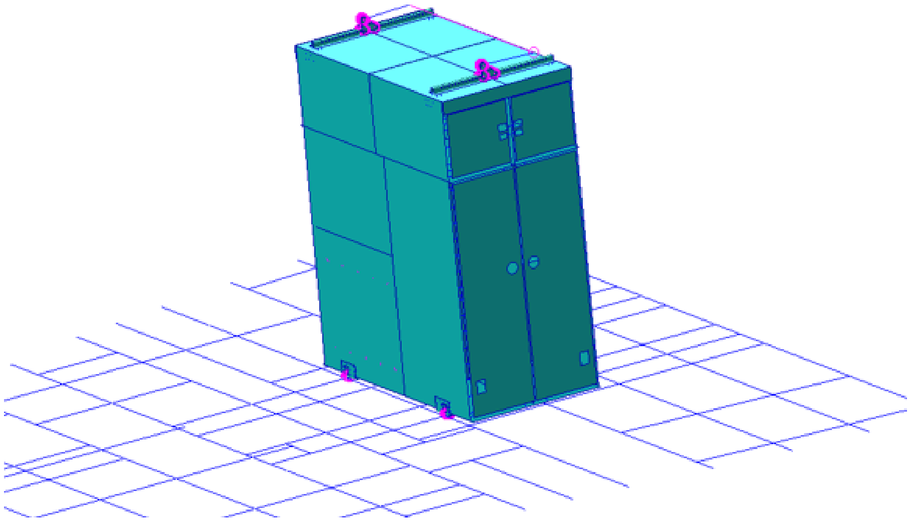


Figure 3 CC Finite Element Model.

The CLOSET Panels are jointed to each other using Dog-Bones and Tab & Slot connections. Dogbones joining Closet panels are modeled with zero length CBUSH elements with all three translational spring constants equal to 10^8 lb/in per IRC Guideline. The CBUSH element has two nodes (one on each panel). Typical view of Dogbones idealization is presented on Figure 22 The Dog-Bone is presented in the Figure 2.2.

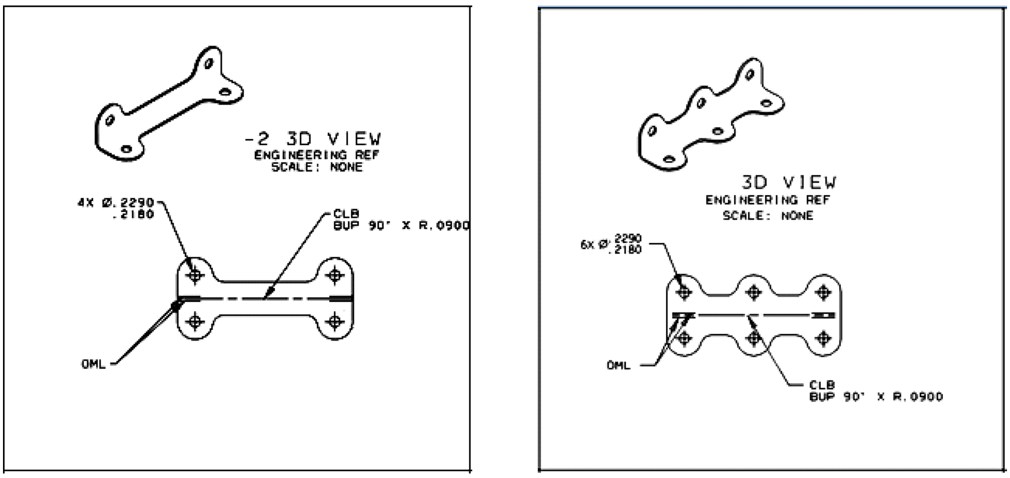


Figure 4. Dog-Bone

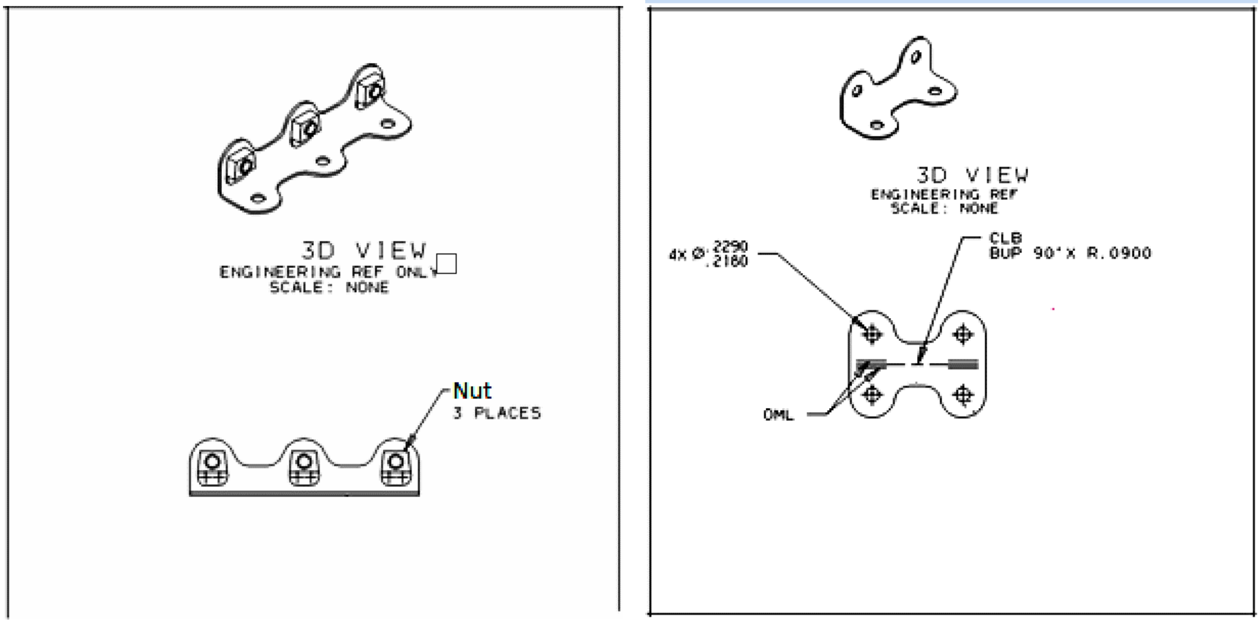


Figure 4 Dog-Bone.

The Tab & Slot are modeled using SmartBush tool. The stiffness coefficients for both Mortice and Tenon and Blind Rabbet joint is presented on Figure 3.3.

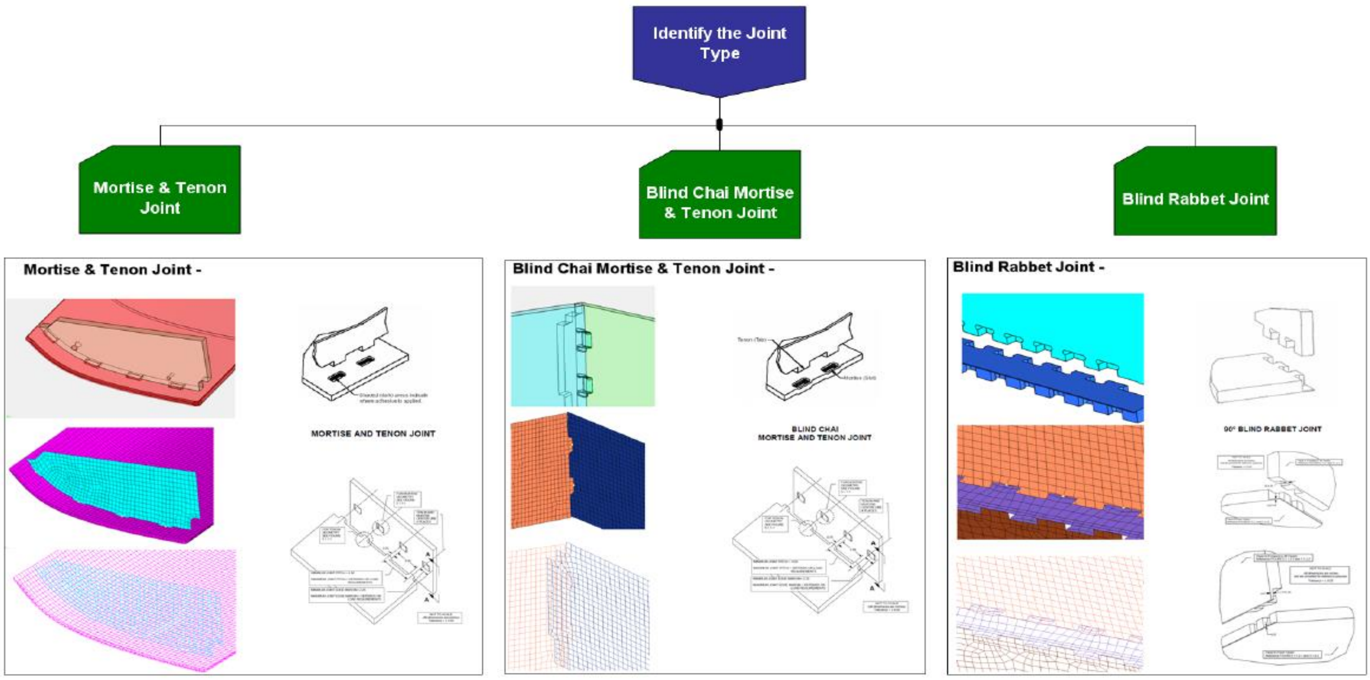


Figure 5 Tab & Slot connection.

FEM of Closet consists of panels joined together with tab slots, dogbones and angles. All panels are modeled with Shell CQUAD elements. The doors are attached to the Closet Forward and Aft Faces with Hinges modeled with CBUSH elements. The Closet is attached to the aircraft floor grid through four brackets and to the Lattice through two tie-rods. Modeling details are shown on **Ошибка! Источник ссылки не найден.**.

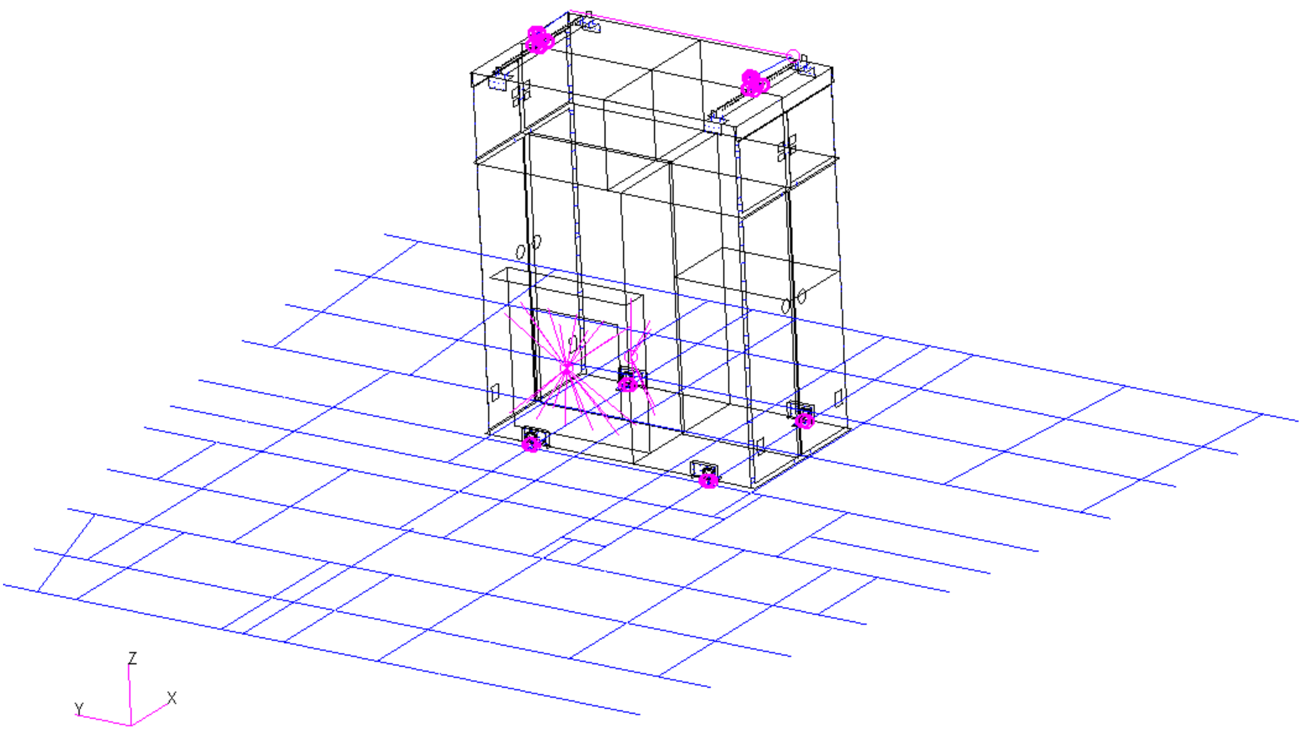


Figure 6 FEM Global View

The FEM has been developed with typical elements: CBAR, CQUAD4, CTRIA3, and CBUSH. The majority of the mesh is approximately 0.5” square elements. The finite element numbering convention is provided in Table 1

MSC Nastran offers various ways of modeling structural connections and fasteners. Bolts, screws, and so on can be represented, depending on the modeling goals, either with flexible springs or bars (BUSH, BAR), rigid elements (RBE2, RBE3), or multipoint constraints (MPC). Connections can be established with ease between points, elements, patches, seam lines, dissimilar meshes, or any of their combinations. The connector elements are general in purpose, easy to generate and always satisfies the condition of rigid body invariance.

BUSH elements is a generalized spring-damper elements. They relate to structural scalar elements. BUSH element connects two non coincident grid points, or two coincident grid points or one grid point. The BUSH avoids the internal constraint problem.

BAR elements are straight one-dimensional elements that connect two grid points. The one-dimensional elements are used to represent structural members that have stiffness along a line or curve between two grid points.

Calculation with BAR elements requires more computing power then RBE2 elements, because every BAR element has 6 DOF and every RBE2 element has 3 DOF, but BAR element gives more accurate result.

2.4. Suggested steps and clues

Keeping in mind the following "Closet Group Nastran/Patran FEM Standards"

• Geometry

Most of the closet finite element models is going to be created meshing surfaces, therefore , before starting any meshing a complete wireframe should be created in patran or imported from catia.

- For all the panels except the floor, the mid plane is modeled
- For the floor panel the lower Face is modeled.

Create additional Geometry for Meshing.

- Create points to created Mesh seeds and hard points
- Brake curves and surface to make simpler surfaces

• Generate Groups

- Create different groups for each individual panel (forward, aft …)
- Create groups for panel joints, lower fittings, overhead fittings, hinges etc

• Meshing

- Choose an appropriated element size according to the closet construction.

A recommended size is 1.5 x 1.5, since the tab and slot distance is 3 or 4.5 in.

- The lower fitting region may require a finest mesh (about 1 in), so it is recommended to star the meshing at this point.
- Create a grid at each tab or dogbone position. For Other kind of brackets is up to the analyst to use more than one grid point connection
- IsoMesh meshing is recommended.
- It is recommended to have a good numbering systems. The Analyst should be able to tell from the element/grid number the location (panel) of each element/grid.

• Mesh Verification

- Since pressure is going to be applied on the panels, it is required to verify the element normal to make sure that all the element in the same panel have the same one.

Patran offers to two different meshers (isomesh – paver). Most of the closet surfaces can be modeled using isomesh, which create a more regular mesh. However there are some surfaces that may need a paver mesh.

• Joints.

All the joints are modelled using spring elements (Patran has some useful utilities to help in the creation of these spring elements)

• Material

• Properties

• Loads and Boundary Conditions .

Loads are applied using different ways (mass elements, pressure loads, point loads etc):

• Load Case Setup

• Analysis Setup and Submission

• Post Processing

. Displacements

. Fringe Plots

. Market Plots

. Reports

. Freebody Plots

3. Analysis

The Closet consists of panels jointed together with tab-slots and dogbones. The location of panels is shown on

Figure **6** below.

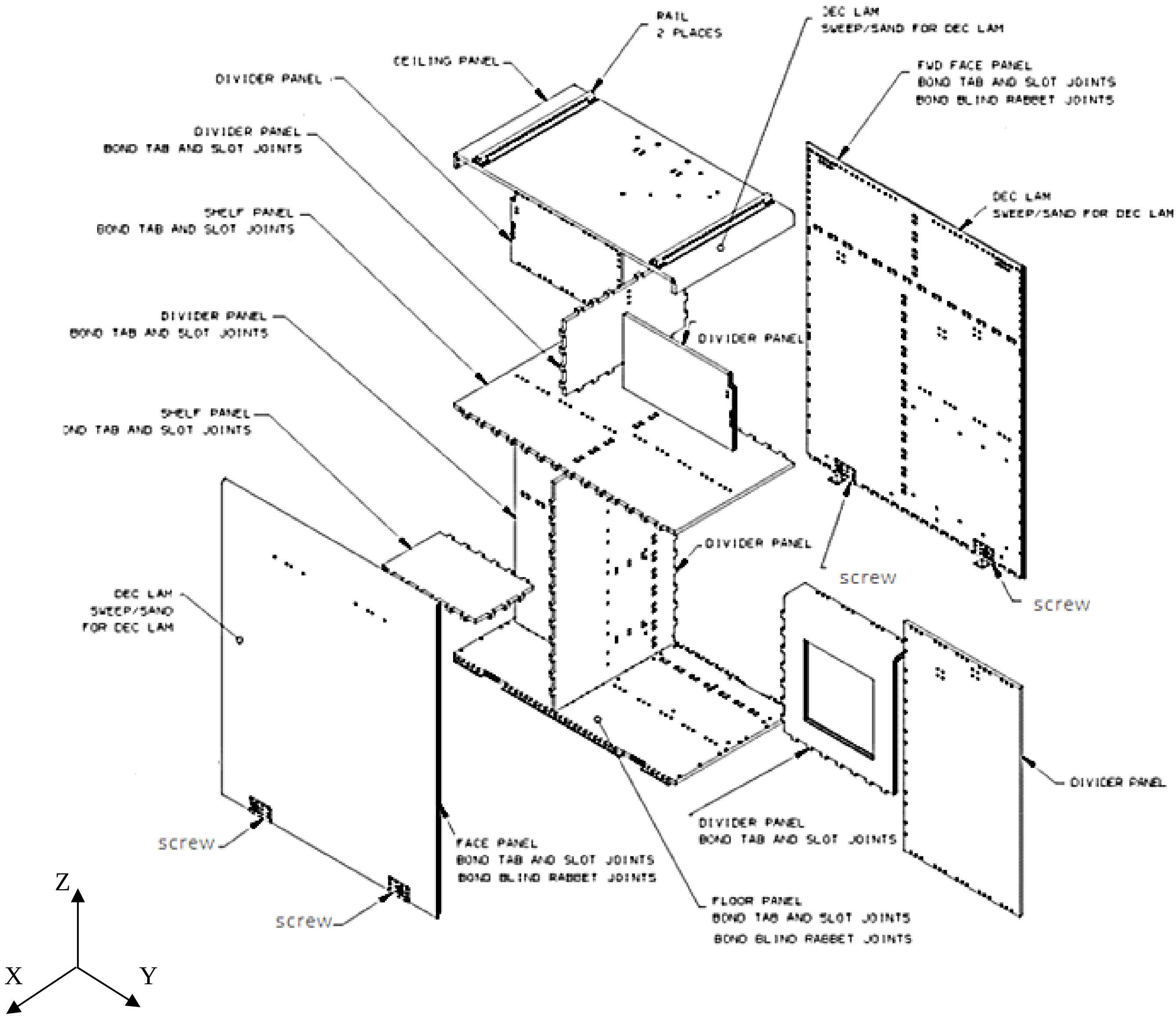


Figure 6. C1 Closet Exploded View

The Closet is attached to the seat track at four locations through identical brackets as presented on Figure and to the Ceiling Structure through two identical Tie Rods as shown on the Figure on next page.

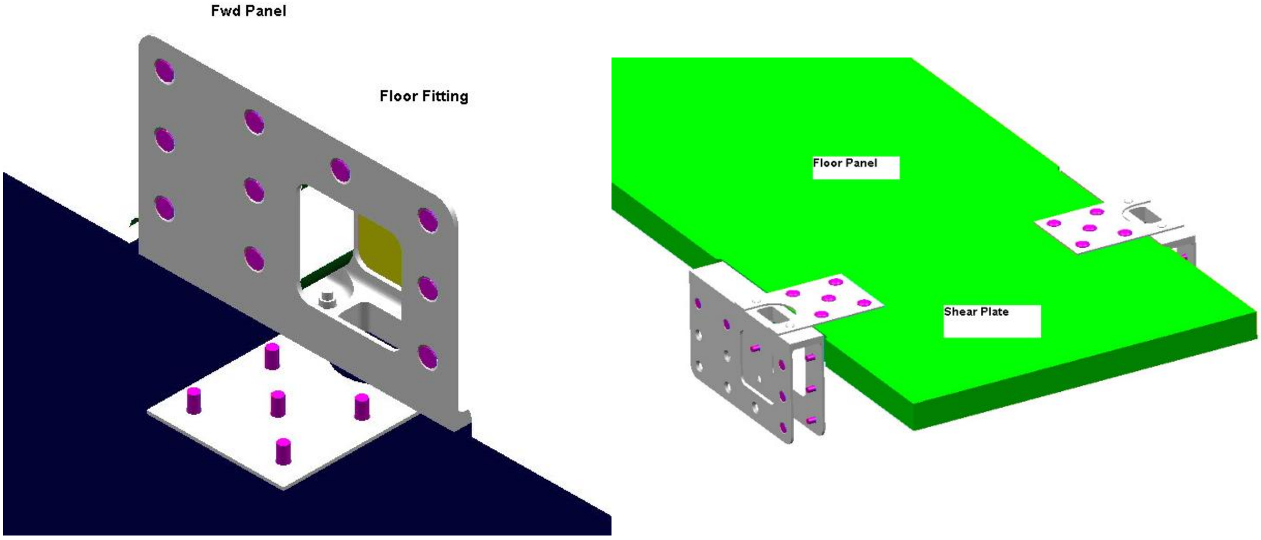


Figure 7. Closet Attachment to the Seat Tracks

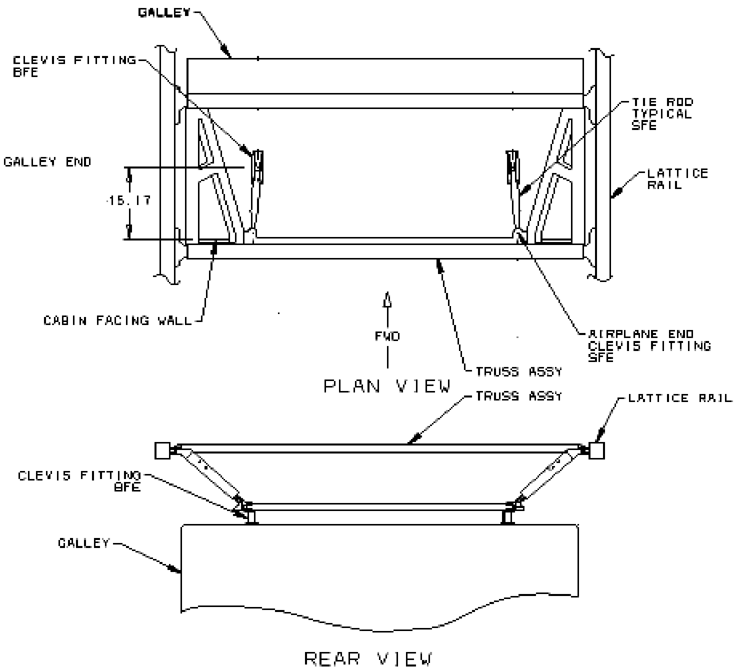


Figure 8. Typical Attachment to Ceiling Structure

The Closet Installation is subjected to interior load requirements per FAA and Boeing requirements.

Material and Allowables

Detail with correspondent material codes, and stock thickness are presented in Table below.

Materials and Allowables for metallic parts are presented in Table 2, and for non-metallic parts in Table .

Table 1 Materials for Analyzed Details

Description	Material	Thickness (Stocksize)
Panel Assy - Face AFT	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Face FWD	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Floor	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Ceiling	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Divider	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Divider	Phenolic	0.011

	Prepreg	
	Honeycomb Core	0.95
Panel Assy - Divider	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - RH Shelf	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - RH Shelf	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Folded Divider	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - Divider	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - RH Shelf	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Panel Assy - RH Shelf	Phenolic Prepreg	0.011
	Honeycomb Core	0.95

Main Door Panel Assy	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Main Door Panel Assy	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Upper Door Panel Assy	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Upper Door Panel Assy	Phenolic Prepreg	0.011
	Honeycomb Core	0.95
Rail Plate	7075-T73511 Extruded Shape	1.5
	7075-T73 Bare Sheet	0.032
Support Fitting-1	7050-T7451 Bare Plate	1.5
Shear Plate-1	7075-T73	0.063
Support Fitting-2	7050-T7451 Bare Plate	1.5
Shear Plate-2	7075-T73	0.063
Support Bracket	7050-T7451	2
Support Bracket	7050-T7451	2
Skid Plate	Phenolic Prepreg	0.011

Skid Plate	Phenolic Prepreg	0.011
Spacer	2024-T3 Bare Sheet	0.125
Angle	6013-T6 Sheet	0.05
Angle	6013-T6 Sheet	0.05
Angle	6013-T6 Sheet	0.05
Angle	6013-T6 Sheet	0.05
Bracket	7075-T6 Extruded Shape	0.1
Bracket	7075-T6 Extruded Shape	0.156

Table 2 Metal Parts Materials and Allowables

Detail P/N	Material	Stock size thickness, in	Basis	Ftu LT ksi	Fsu LT ksi	Fbru 1.5 ksi	nu	E, 10^6 psi	G, 10^6 psi
Rail	7075-T73511 Extruded Shape	1.5	B	69	40	96	0.33	10.4	4.0
Plate	7075-T73	0.032	B	69	39	97	0.	10	3.

	Bare Sheet						33	.3	9
Support Fitting	7050-T7451 Bare Plate	1.5	B	76	43	101	0.33	10.3	3.9
Shear Plate	7075-T73 Bare Sheet	0.063	B	69	39	97	0.33	10.3	3.9
Support Bracket	7050-T7451 Bare Plate	2	B	76	44	103	0.33	10.3	3.9
Support Bracket-2	7050-T7451 Bare Plate	2	B	76	44	103	0.33	10.3	3.9
Spacer	2024-T3 Bare Sheet	0.125	B	64	40	95	0.33	10.5	4.0
Angle-1	6013-T6 Sheet	0.05	B	56	35	83	0.33	9.9	3.8
Angle-2	6013-T6 Sheet	0.05	B	56	35	83	0.33	9.9	3.8
Angle-3	6013-T6 Sheet	0.05	B	56	35	83	0.33	9.9	3.8
Angle-4	6013-T6 Sheet	0.05	B	56	35	83	0.33	9.9	3.8
Bracket-1	7075-T6 Extruded Shape	0.1	B	79	44	105	0.33	10.4	4.0

Bracket-2	7075-T6511 Extruded Shape	0.156	B	79	44	105	0.33	10.4	4.0

All Closet Panels are 1inch Fiberglass Sandwich Honeycomb Panels. FWD and Aft Face Panels have a bonded Core splice. Properties for all Non-Metallic Parts are shown in Table . Panels Stack-up is shown on Figure .

Table 3 Non-Metallic Parts Materials And Allowables

Part name	**Material Definition**		**Allowable**
Honeycomb Panels	Core	Nomex -1 Thickness=0.95 in	Shear: F_{SL}= 138 psi F_{SW}= 76 psi
	Facesheet	Phenolic/Fiberglass-1 Thickness = .011in	Compression FILL: Fc = 28 ksi WARP: Fc = 26 ksi Tension Ft = 35 ksi
Honeycomb Panels at Bonded Core Splice	Core	Nomex-2 Thickness=0.95 in	Shear: F_{SL}= 100 psi F_{SW}= 74 psi
	Facesheet	Phenolic/Fiberglass-2	Compression FILL: Fc = 17

		Thickness = .011in	ksi WARP: Fc = 21 ksi Tension Ft = 35 ksi

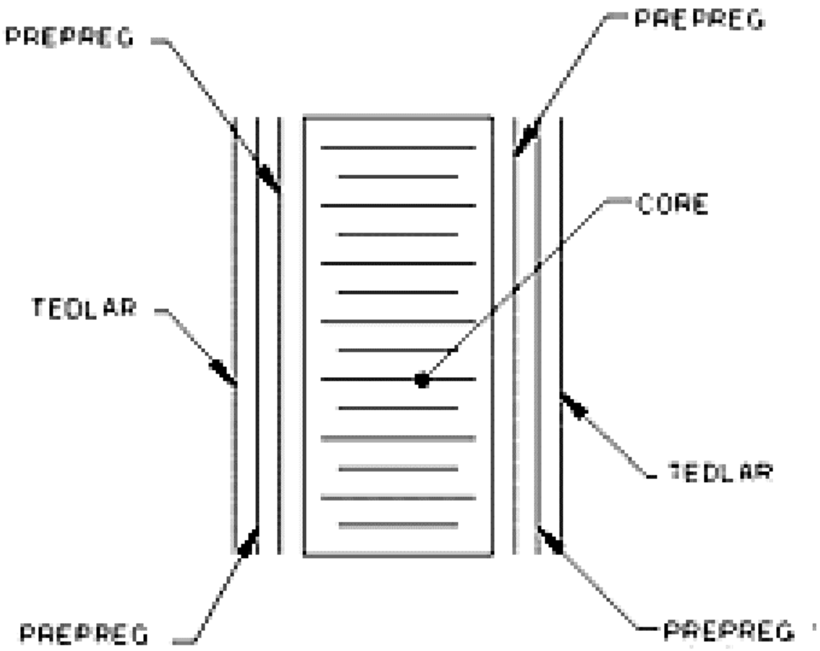


Figure 9 Centerline Closet Sandwich Panels Stack-Up

Material properties for fiberglass facesheets and Nomex Honeycomb core are shown in Table below.

Table 4 Panel Material Properties

	Phenolic/Fiberglass	Nomex Honeycomb .95" thick -3 lb./ft.^3
Drawing	Phenolic Prepreg	Honeycomb Core
Elastic Modulus E22, Fill Tension	2980000	100
Elastic Modulus E11, Warp Tension	3180000	100
Elastic Modulus E22, Fill Compression	3140000	100
Elastic Modulus E11,Warp Compression	3330000	100
Poisson Ratio, $\upsilon 12$	0.13	0.13
Shear Modulus, G12	680000	100
Shear Modulus, G23 (Gw)	100	3700
Shear Modulus, G13 (G_L)	100	6417

Allowables for the inserts used in Closet Installation are shown in Table below.

Table 5 Insert Allowables

Insert type	Core Material	Face sheet plies	ED	Pull out 90°, lbs	Shear, lbs
INSERT-1	Nomex	2	0.5	238	239
INSERT-1	Nomex/Foam	2	0.5	216	310
INSERT-1	Foam	2	0.5	266	325
INSERT-1	Foam	2	1.5	266	553
INSERT-1	Nomex	2	1.5	238	375
INSERT-7	Nomex	2	1.5	238	375
INSERT-4	Foam	2	0.5	318	310

INSERT-4	Nomex/Foam	2	0.5	318	310
INSERT-4	Nomex	2	1.5	318	245
INSERT-2	Nomex	2	1.5	238	375
INSERT-5	Foam	2	0.5	449	385
INSERT-5	Foam	2	1.5	449	495
INSERT-3	Nomex	2	1.5	238	375
INSERT-6	Nomex	2	0.5	318	245

There are two types of tab-slots used in Closet Installation. They are as follows:

- Blind Rabbet joint – joining Floor Panel with Forward/Aft Panels;
- Mortise & Tenon joint – joining most of the panels together.

Materials and allowables for bolts and nuts used in Closet Installation are presented in Table 6 below.

Table 6 Fastener Materials and Allowables

Part	Description	D, in	Material	Allowable	
				Shear, lbs	Tension, lbs
SCREW-1	Machine Screws	0.19	A286 CRES	2690	2320
SCREW-2	Screw	0.19	A286 CRES	2690	2320
SCREW-3	Machine Screws	0.164	A286CRES	2000	1600
BOLT-1	Bolt, Protruding Head	0.164	6Al-4V Titanium	2000	1160
BOLT-2	Bolt	0.4375	A286 CRES	16500	25800
BOLT-3	Bolt, Hex Head	0.19	6Al-4V Titanium	2690	3620
BOLT-4	Bolt, 100 Deg Cross	0.19	6Al-4V Titanium	2690	3120

BOLT-5	Bolt, Blind, 100 Deg Red HD	0.19	6Al-4V Titanium	2690	1800
NUT-1	Nut	0.4375	Cadmium Plated CRES	-	24900
SCREW-4	Screw, 100 Deg Head	0.164	6Al-4V Titanium	2000	1970
SCREW-5	Fairing Screws	0.19	6Al-4V Titanium	2690	2760
BOLT-6	Bolt, Hex Head	0.3125	A286 CRES	7250	7700
BOLT-7	Bolt	0.3125	A286 CRES	7250	4640
BOLT-8	Bolt, Hex Head	0.5	A286 CRES	18600	16200
NUT-2	Nut, Self-Locking	0.25	Cadmium Plated CRES	-	4270
NUT-3	Nut, Self-Locking	0.4375	Cadmium Plated CRES	-	14100
WASHER-1	Washer, Countersink, Oversize	0.317	A286 CRES	-	-
WASHER-2	Washer	.442	A286 CRES	-	-
WASHER-3	Washer, Plain	.340	A286 CRES	-	-

Section Properties

Rails are made from Standard Profile shown on Figure below.

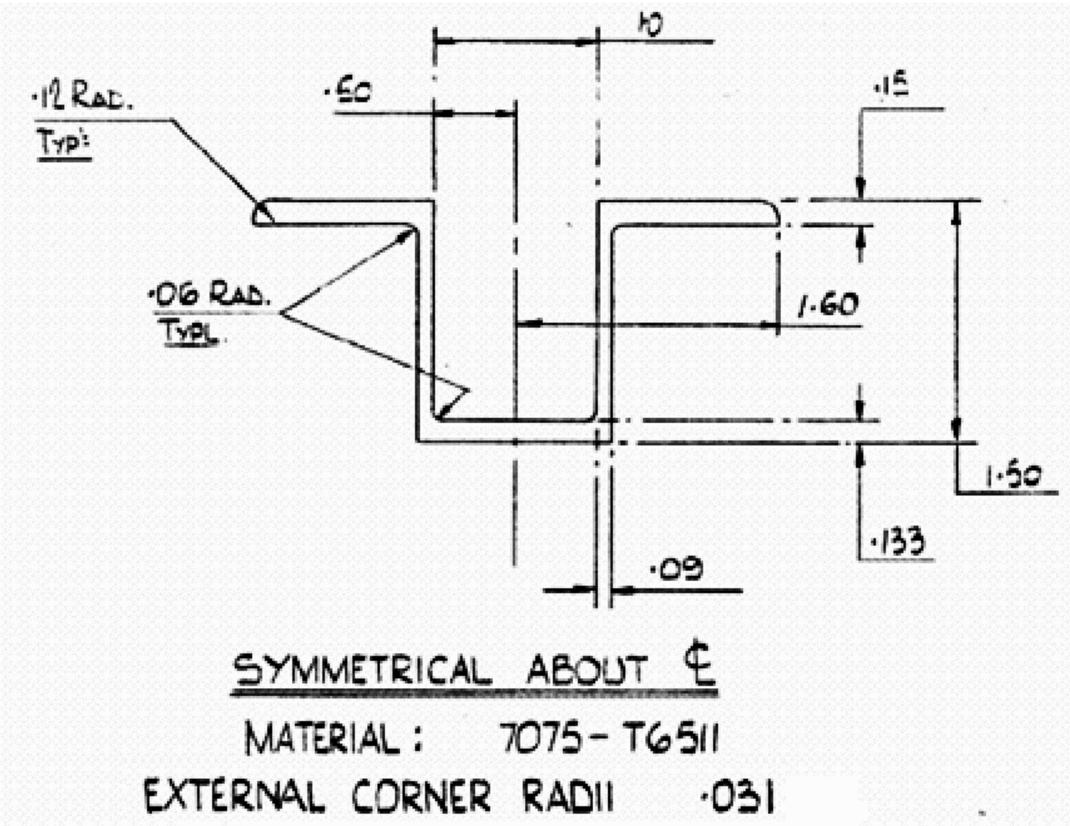


Figure 10. Profile

This profile has fastener holes drilled as shown on Figure .

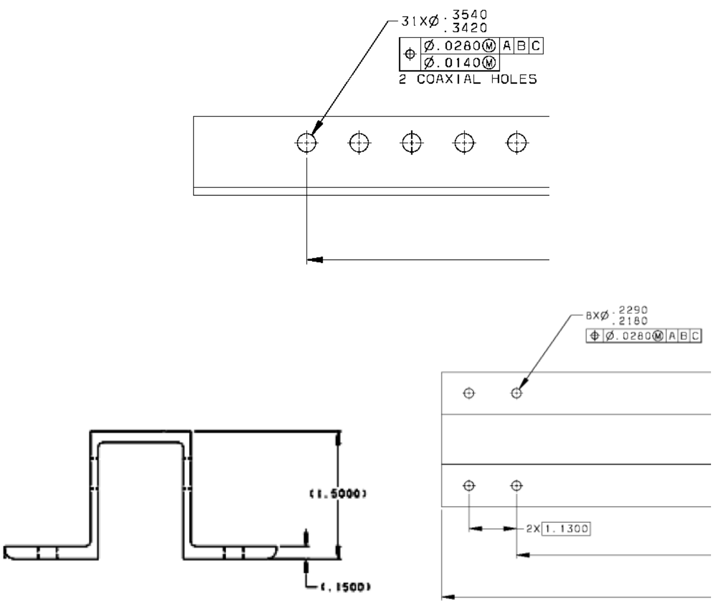


Figure 11 Cross Section of Rails

Bracket is used to attach Turn Retainer to the Folded Divider . This part is made from Standard Profile shown on Figure 12 below.

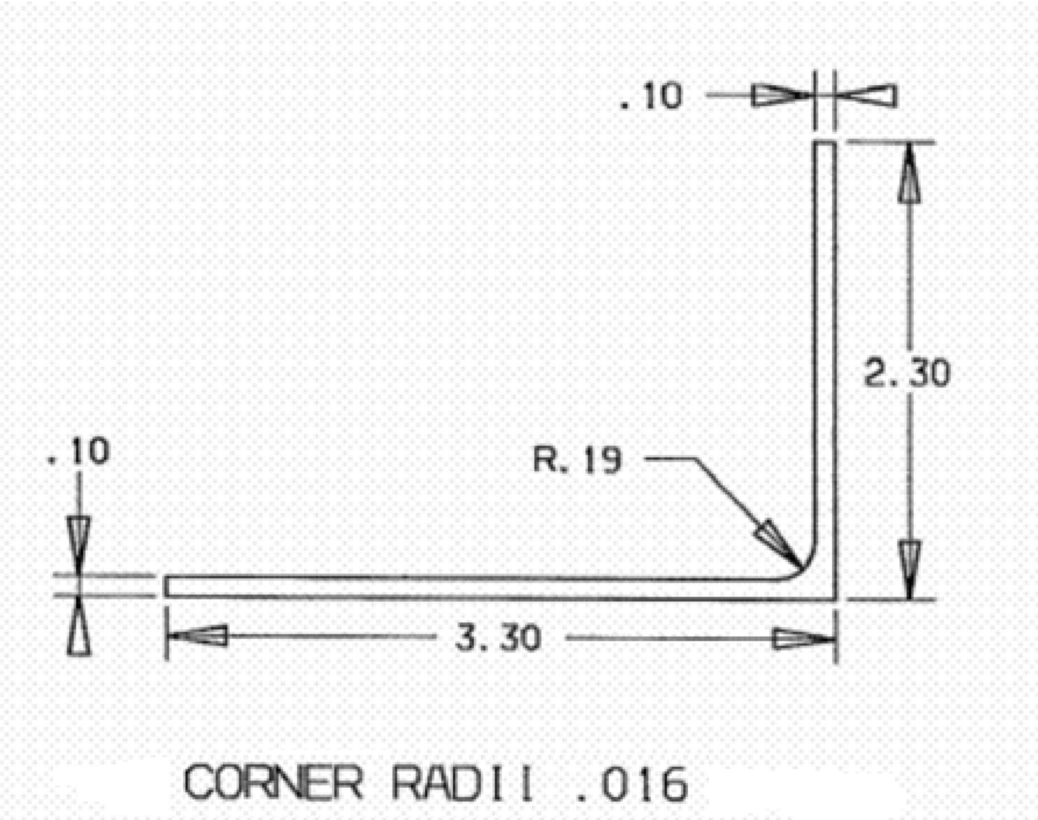


Figure 12 Standard Profile

Support Bracket is used to join FDW/AFT Face panels with Ceiling. This parts are made from Standard profile shown on Figure 13 below.

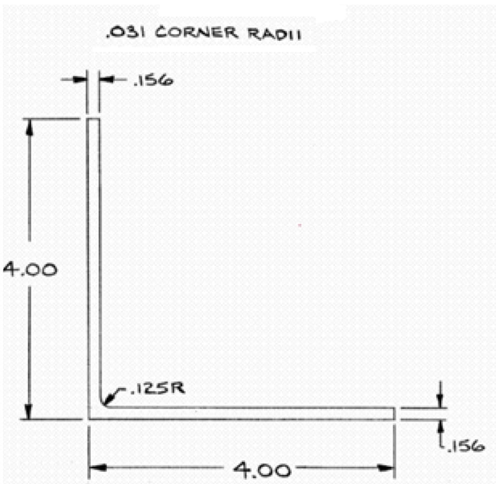


Figure 13. Standard Profile of Support Bracket

This profile has fastener holes drilled as shown on Figure 4.

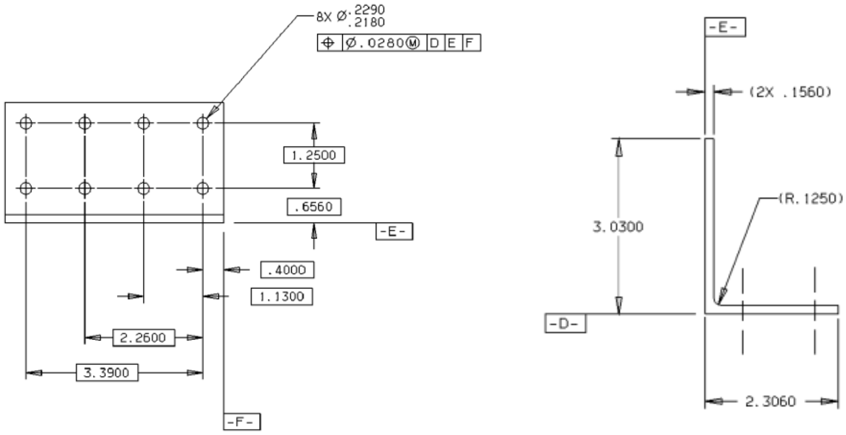


Figure 14 Cross Section of Support Bracket

Dogbomes used to attach Closet Panels are shown on **Figure** 15 below.

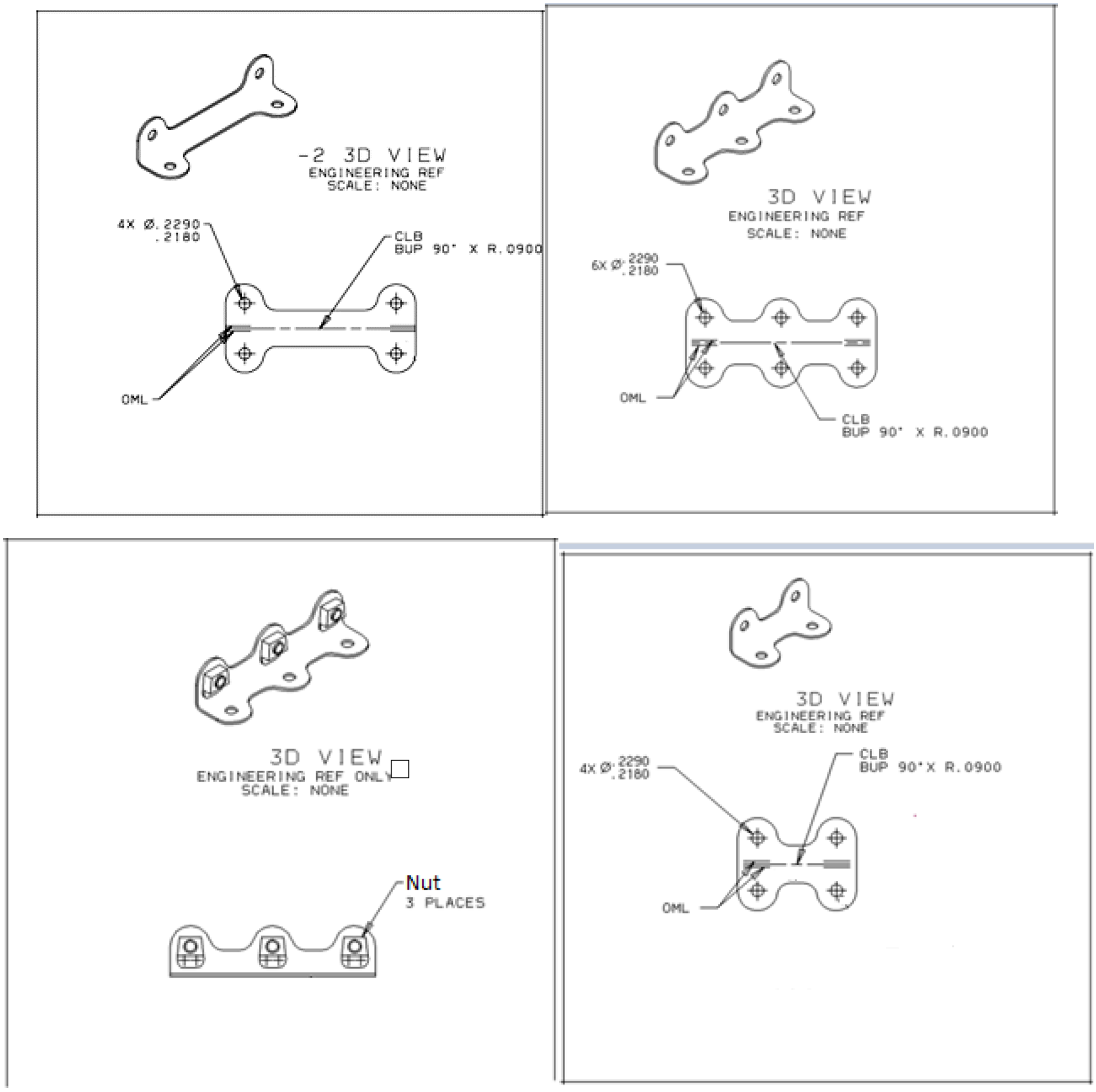


Figure 15 Angles Overview

Lower Support Brackets is shown on **Figure 16** below.

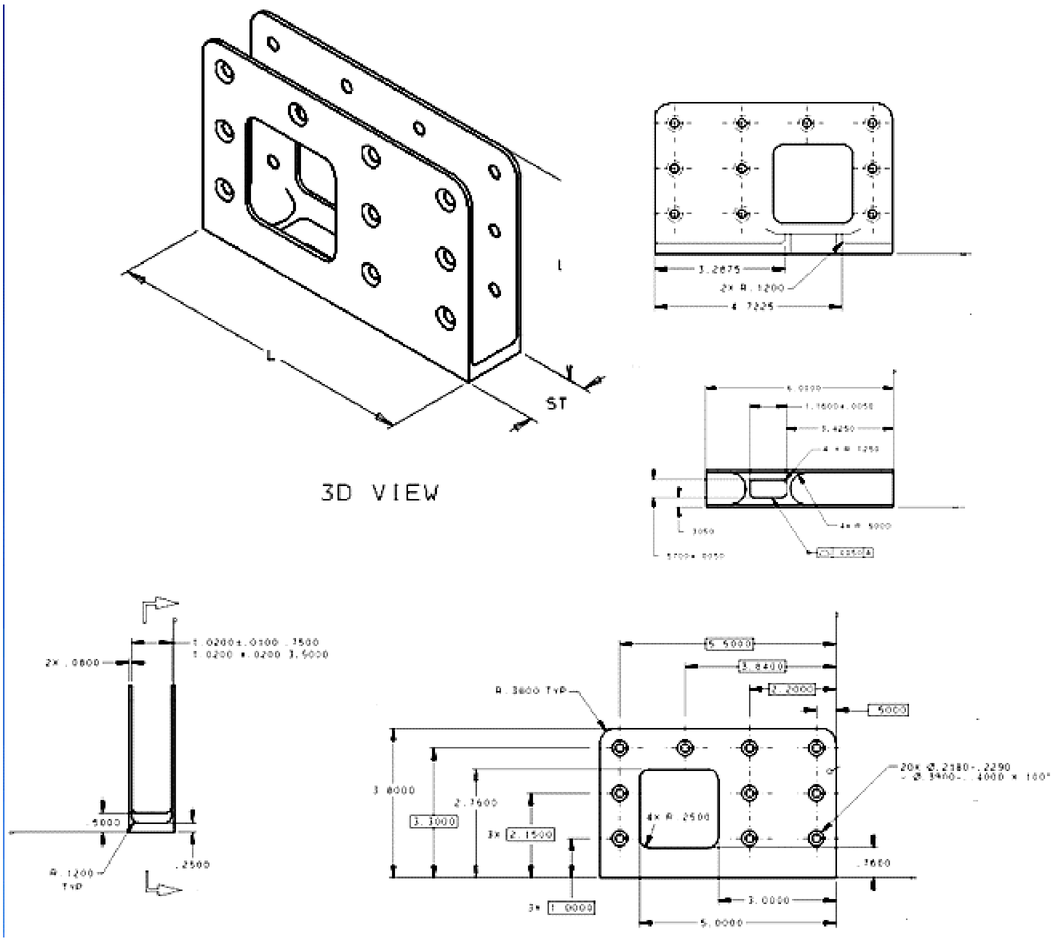


Figure 16 Lower Support Fitti

Upper Tie-Rod Support Brackets is shown on Figure 17 below.

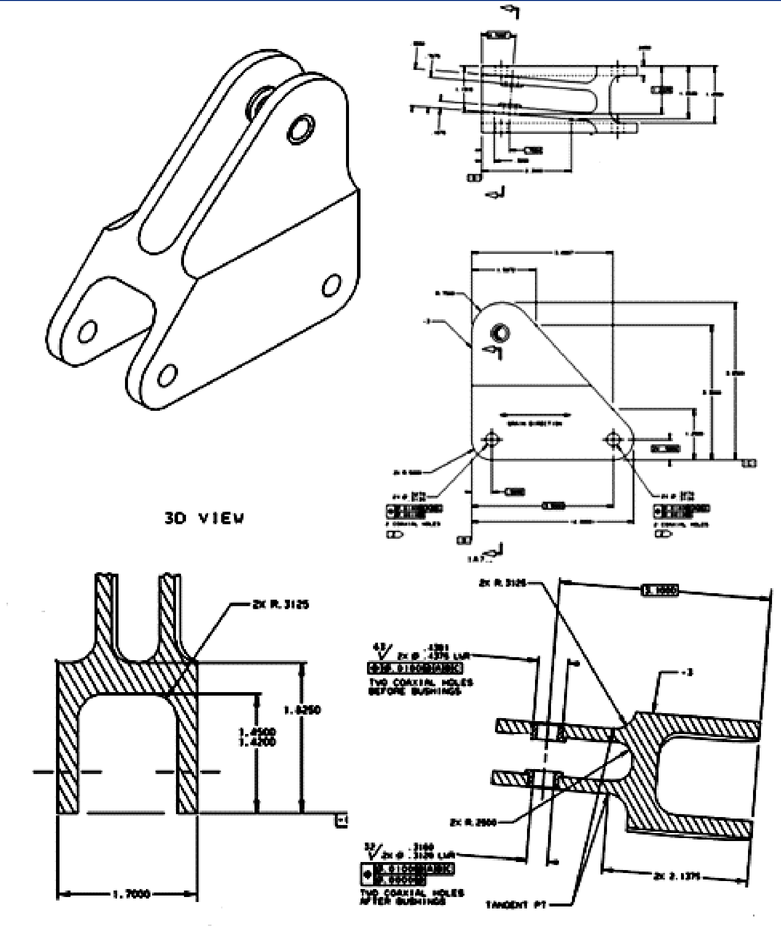


Figure 17 Upper Tie-Rod Support Bracket

Weight and Design Loads

This section presents the weight and loads applied to the Centerline Closet .

Weight and Center of Gravity

The weight and center of gravity of the Centerline Closet assembly is presented below.

Table 7 Weight and Center of Gravity for Closet Installation

Empty Weight & CG @ Assembly Level				
Category	Weight (lbs)	Center of Gravity (in)		
		STA (X)	BL (Y)	WL (Z)
Structure Total	**297.87**	**378.42**	**0.69**	**242.91**
Primary Structure	177.46	379.00	*-0.02*	242.67
Additional Structure	93.33	377.00	2.43	243.50
Structure Sub-Total	270.79			
10% Allowance Factor	27.08			

Loaded Weight & CG @ Installation Level				
Loading Conditions	Weight (lbs)	Center of Gravity (in)		
		STA (X)	BL (Y)	WL (Z)
Single Loading Condition	**798.77**	**379.06**	**0.13**	**244.32**

Table 8 Equipment and Content Weight and C.G

Equipment & Content

Equipment & Content TOTALS				
Loading Conditions	Center of Gravity (in)			Weight (lbs)
	STA (X)	BL (Y)	WL (Z)	
Single Loading Condition	**379.45**	**-0.20**	**245.16**	**500.90**

Equipment & Content Loads						
Type	Fixed/ Loose	Description	Center of Gravity (in)			Weight (lbs)
			STA (X)	BL (Y)	WL (Z)	
Normal	Fixed	WHEELCHAIR	373.49	4.82	218.97	30.90
Normal	Fixed	Trolly	363.85	14.60	218.20	23.00
Normal	Loose	FLOOR LOAD LH FWD	369.75	*-17.25*	216.70	40.00
Normal	Loose	COAT ROD LOAD LH FWD	369.79	*-22.25*	258.12	50.00
Normal	Loose	FLOOR LOAD LH AFT	388.25	*-17.25*	216.70	40.00
Normal	Loose	SHELF LOAD LH AFT	388.25	*-17.25*	248.42	25.00
Normal	Loose	FLOOR LOAD RH AFT	389.25	14.25	216.70	50.00
Normal	Loose	COAT ROD LOAD RH FWD	370.07	13.55	256.05	60.00
Normal	Loose	COAT ROD LOAD RH AFT	388.61	13.55	256.05	60.00
Normal	Loose	UPPER SHELF LH FWD	369.75	*-16.00*	272.31	25.00
Normal	Loose	UPPER SHELF LH AFT	388.25	*-16.00*	272.31	25.00
Normal	Loose	UPPER SHELF RH FWD	369.75	16.00	272.31	25.00
Normal	Fixed	UPPER SHELF RH AFT	388.25	16.00	272.31	25.00
Normal	Fixed	ARO Brand Panel	398.00	0.00	262.44	22.00

FAA Requirements

Design loads for Aircraft Closet installation per FAA 14CFR 25.561 and additional combined loading cases listed below:

Table 9: FAA Load Factor Requirements

Load Attitude	**14CFR 25.561 Amdt 25-91**	**Analysis (Maximum) Load Factor**
Forward	9.0G	9.0G
Down	6.0G	6.0G
Side	3.0G	3.0G
Up	3.0G	3.0G
Aft	1.5G	1.5G
Side + Down	----	1.6G Side + 1.5G Down
Up + Forward	----	1.5G Up + 0.8G Forward 2.4G Up + 0.5G Forward
Up + Aft	----	2.4G Up + 0.5G Aft
Down + Forward	----	3.8G Down + 1.5G Forward 5.6G Down + 0.8G Forward 7.0G Down + 0.5G Forward
Down + Aft	----	7.0G Down +0.5G Aft 3.0G Down + 1.5G Aft

Decompression

Decompression for all compartments is calculated by equations and presented:

Vent area (A) – 7.15 in^2

Compartment volume (V) - 22.03 ft^3

Values are presented for vent area of 5 and 10 in^2 and volume of 20 and 25 ft^3.

1. Interpolating vent area between 5 and 10 to obtain value for V=20, A = 7.15 :

Pressure = 0.49 -(7.15-5)/(10-5)*(0.49-0.17)= 0.35

2. Interpolating vent area between 10 and 20 to obtain value for V=25, A = 7.15 :

Pressure = 0.68 - (0.25-0.68)*((7.15-5)/(10-5)) = 0.50

3. Interpolating volume between 25 and 50 using values from previous steps to obtain value for V = 22.03, A = 7.15:

Pressure = 0.35 + (0.50-0.35)*((22.03-20)/(25-20) = <u>0.41</u>

Table 10 Decompression pressure interpolation

DIFFERENTIALS (PSI) FOR MAIN CABIN MONUMENT COMPARTMENTS (AFT OF DOOR 1) THAT VENT TO THE MAIN CABIN ONLY

	Vent area (in^2)*												
Volume (ft^3)	0	1	2	3	4	5	10	20	30	40	50	60	70
1	8.6	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	8.6	0.22	0.06	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	8.6	0.41	0.13	0.06	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
4	8.6	0.64	0.22	0.11	0.06	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
5	8.6	0.68	0.25	0.12	0.07	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00
10	8.6	1.80	0.68	0.38	0.25	0.17	0.05	0.01	0.01	0.00	0.00	0.00	0.00
15	8.6	2.81	1.23	0.68	0.45	0.33	0.10	0.03	0.01	0.01	0.01	0.01	0.01
20	8.6	3.61	1.80	1.05	0.68	0.49	0.17	0.05	0.02	0.01	0.01	0.01	0.01
25	8.6	4.22	2.33	1.43	0.95	0.68	0.25	0.07	0.03	0.02	0.01	0.01	0.01
50	8.6	5.91	4.21	3.09	2.33	1.80	0.68	0.25	0.12	0.07	0.05	0.03	0.03
75	8.6	-	-	-	-	2.81	1.23	0.45	0.25	0.15	0.10	0.07	0.05
100	8.6	-	-	-	-	3.60	1.80	0.68	0.38	0.25	0.17	0.12	0.09
125	8.6	-	-	-	-	4.21	2.33	0.95	0.52	0.35	0.25	0.19	0.14
150	8.6	-	-	-	-	4.71	2.81	1.23	0.68	0.44	0.33	0.25	0.20

Note: It is permissible to linearly interpolate between points.

Differential pressures for all Closet compartments numbered at Figure 18 are presented in Table 11.

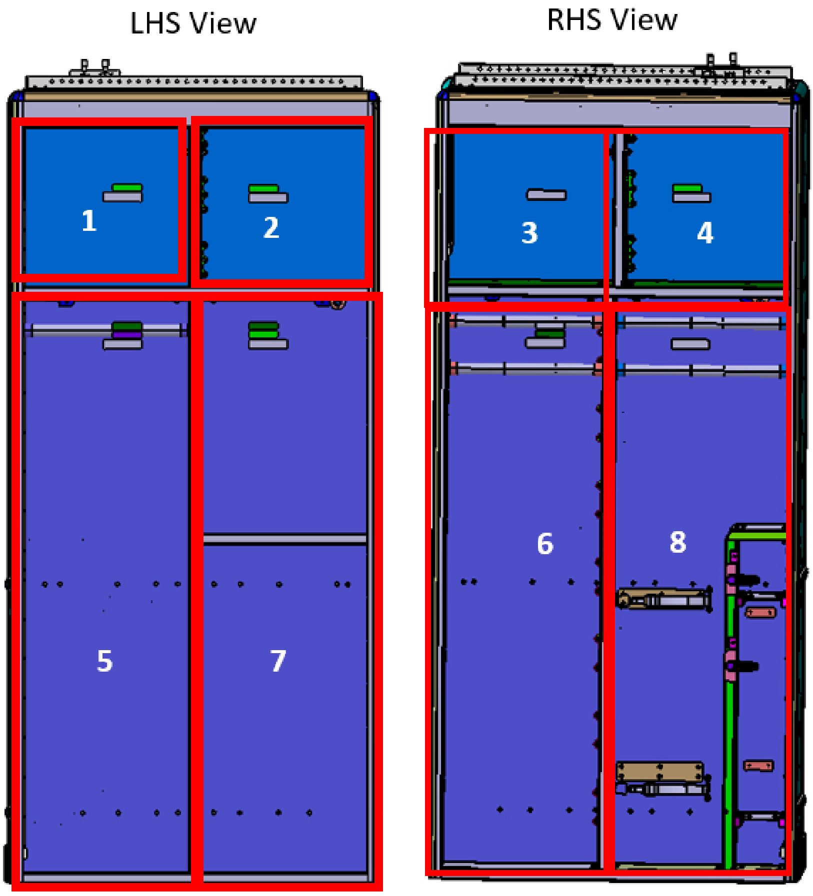


Figure 18. Global View of Closet Compartments (Doors Hidden for Clarity)

Table 11. Differential Pressures Applied to Closet Compartments

Compartment	Volume (ft^3)	Vent Area (in^2)	Max Differential Pressure* (psid)
1	6.28	4.34	0.10
2	6.28	5.21	0.08
3	6.28	4.20	0.11
4	6.28	5.07	0.08
5	17.45	7.53	0.27
6	20.17	7.47	0.34
7	17.16	7.25	0.28
8	22.03	7.15	0.41

Computation

Analysis for all details was performed using FEM and classical hand calculations.

The Closet is attached to the aircraft with two tie rods on top and four U-shape fittings on the bottom.

A Finite Element Model (FEM) is built using MSC Nastran/Patran Software and described.

For the analysis, the attachments are numbered as shown on Figure 9. All panels, fittings, fasteners and inserts are analyzed and minimal margins are presented in Table 25.

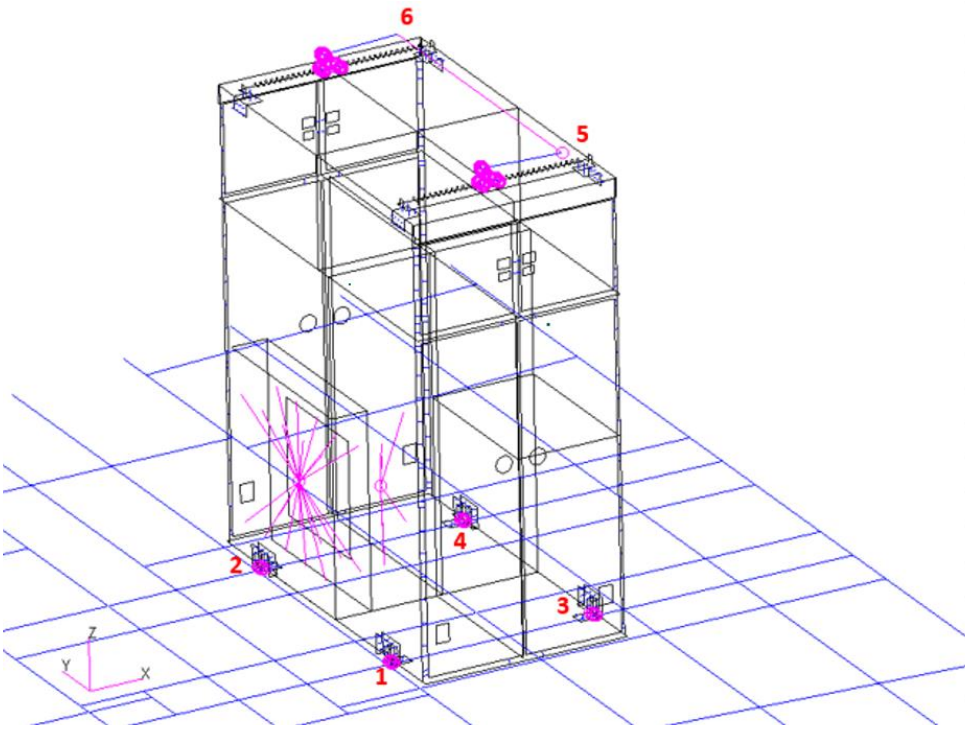


Figure 19. Closet Installation Finite Element Model With Supports

The purpose of this Section is to provide high-level overview of the FE model of the Centerline Closet, its basic principles and idealization. Main goal of this Section is to link modeling data to the basic sources and summarize all assumptions made.

The internal loads extracted from FEM have been used for detailed analysis and to generate interface loads for floors and fuselage groups.

Table 12 Element Numbering Convention

Part	Element Range	Element Type
Panel-1	Element 31008:52057, 52124, 63852:64113	CQUAD4
Panel-2	Elm 9826:25767 25834:28407 28473:31007 63590:63851	CQUAD4
Panel-3	Elm 1:9825	CQUAD4
Panel-4	Elm 52190:63589	CQUAD4
Panel-5	Elm 262540:271445	CQUAD4
Panel-6	Elm 243641:246455	CQUAD4
Panel-7	Elm 64114:73304	CQUAD4
Panel-8	Elm 73339:83624	CQUAD4
Panel-9	Elm 253202:260335	CQUAD4
Panel-10	Elm 249271:253201	CQUAD4
Panel-11	Elm 246456:249270	CQUAD4
Panel-12	Elm 260336:262539	CQUAD4
Panel-13	Elm 83625:86732	CQUAD4
Panel-14	Elm 294601:302980	CQUAD4
Panel-15	Elm 307413:315792	CQUAD4
Panel-16	Elm 302981:305196	CQUAD4
Panel-17	Elm 305197:307412	CQUAD4
Support Fitting-1	Elm 86733:87116 87501:87884	CQUAD4
Support	Elm 574913:609089 620808:653344	TET10

Bracket		
Rail	Elm 87885:89235 89522:89807 90380:90665 91524:91809 92954:93239 94670:94955 96672:96957 98960:99245 101534:101819 104394:104679 107540:107825 110972:111257 114690:114975 118694:118979 122984:123269 127560:127845 132422:132707 137570:137855 143004:143289 148724:149009 154730:155015 161022:161307 167600:167885 174464:174749 181614:181899 189050:189335 196772:197057 204780:205065 213074:243640	CQUAD4
Angle Bracket	Elm 271446:271797	CQUAD4
Shear Plate	Elm 271942:272917	CQUAD4
Tie-Rods	Elm 653369 653370	CROD

The FEM coordinate system is located in the fuselage coordinate system with +X aft, +Y pilot’s right, +Z up. The most common applied loads are pressure and inertia loads. Boundary conditions represent constraints of floor beams at Closet to Seat Track attachment points and tie rods. All part are evaluated using the 101 linear static solver of MSC Patran.

Model Assumptions

The following subsections describe overview of model assumptions.

Tie Rods

Brackets that connect the tie rods to the barrier are modeled as TET10 Solid elements (refer to Figure 20 and Figure 21). Tie rods as simple axial ROD elements.

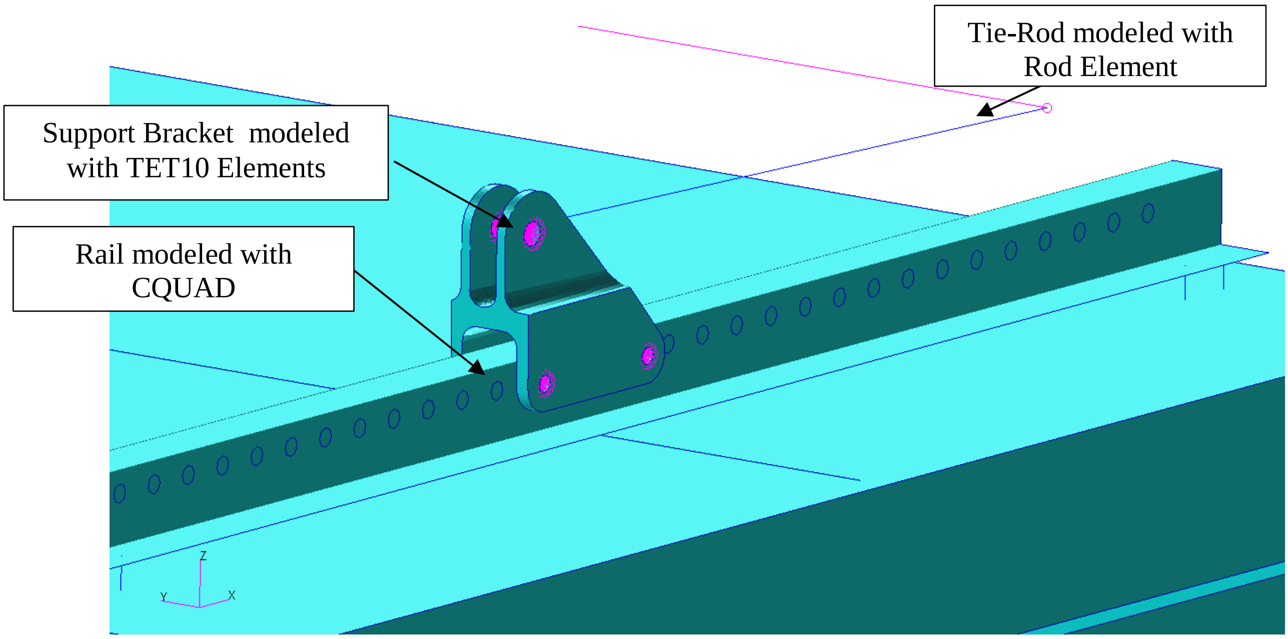


Figure 20 Modeled Tie-Rod Attachment

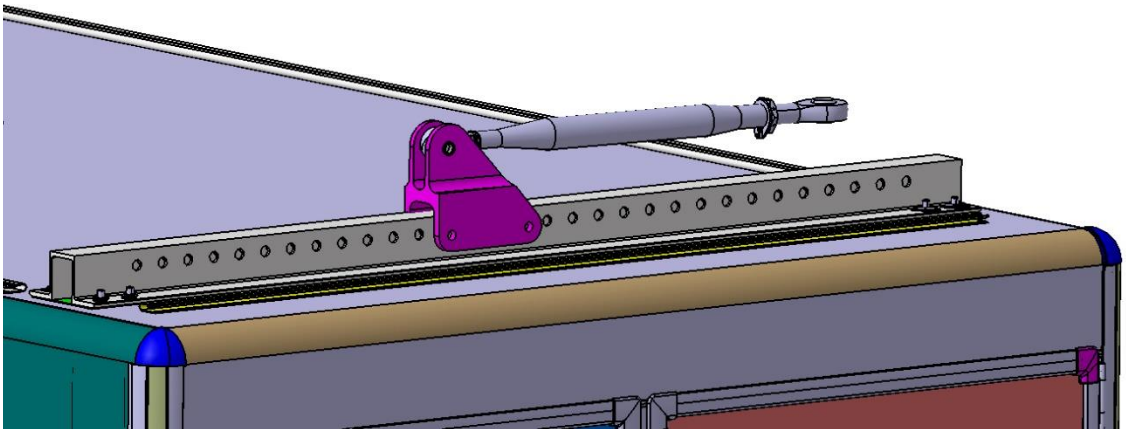


Figure 21 Design of the Tie Rod Attachment

Elements Offset

Panels and door are modeled with elements in the same plane using midsurfaces.

Floor Grid

The Finite element model of the Floor Grid is performed and taken from FEM of Closet previously installed on the same airplane.

Fasteners

Fasteners are idealized with CBAR elements with all three translational spring constants 10^8 lb/in. These elements are used to attach fittings to the panels.

Dogbones

Dogbones joining Closet panels are modeled with zero length CBUSH elements with all three translational spring constants equal to 10^8 lb/in per IRC Guideline. The CBUSH element has two nodes (one on each panel). Typical view of Dogbones idealization is presented on Figure 2222.

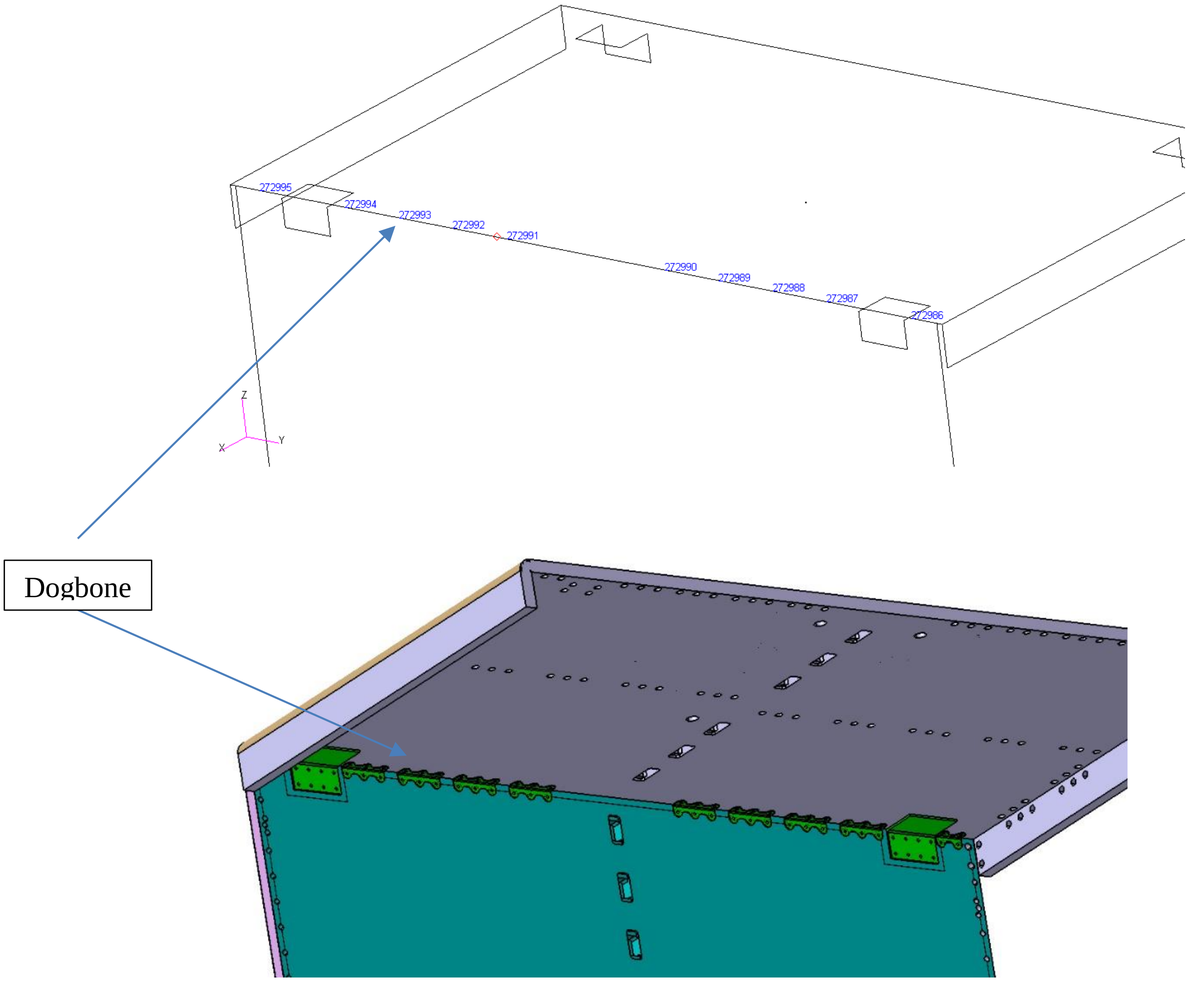


Figure 22 Idealization of Dogbones

Tab and Slots

Dogbones are modeled using Boeing approved SmartBush tool. The stiffness coefficients for both Mortice and Tenon and Blind Rabbet joint is presented on Figure 23.

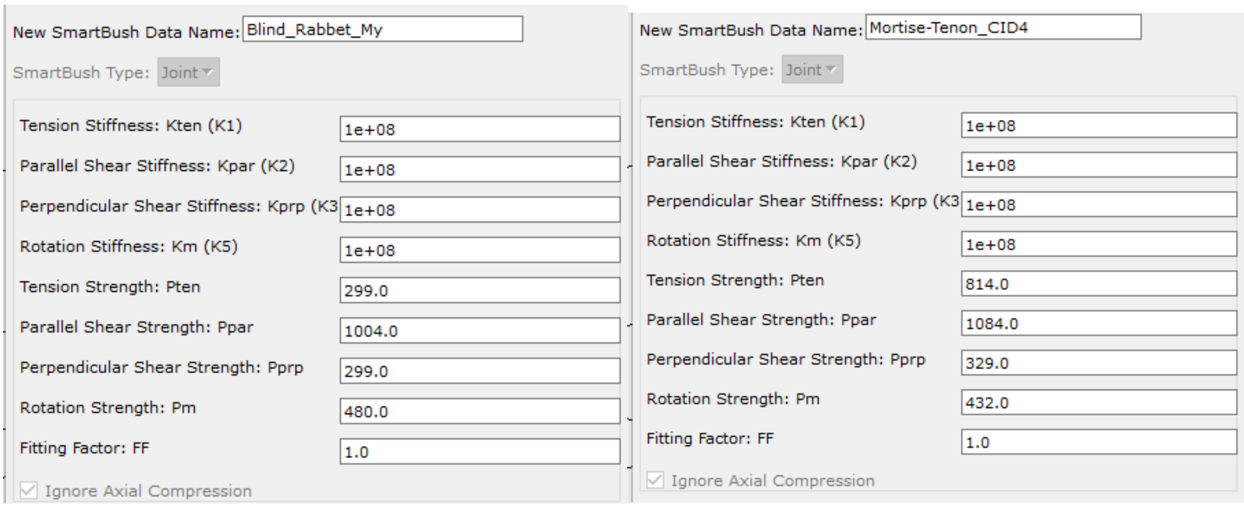


Figure 23 Blind Rabbet (Left) and Mortice and Tenon (Right) Joint Properties

Applied Loads

There are 17 Load Cases in FEM like inertial and decompression loads.

Inertial Loads

These loads applied to the entire model and evaluated with the linear static solver. Inertial Load Cases were selected greater of FAA presented in Table 9 and listed below.

- 9.0 G Forward
- 6.0 G Down
- 3.0 G Right
- 3.0 G Left
- 3.0 G Up
- 1.5 G Aft
- 1.6 G Left + 1.5 G Down
- 1.6 G Right + 1.5 G Down
- 1.5 G Up + 0.8 G Forward
- 2.4 G Up + 0.5 G Forward
- 2.4 G Up + 0.5 G Aft
- 3.8 G Down + 1.5 G Forward
- 5.6 G Down + 0.8 G Forward

- 7.0 G Down + 0.5 G Forward
- 7.0 G Down + 0.5 G Aft
- 3.0 G Down + 1.5 G Aft

Decompression

Load Case "Decompression + 1G Down" includes pressure and inertia loads, pressure have been applied to the panels of each of the eight compartments presented on Figure 1 and in Table .

For all FEM elements a density was set in order to make available inertia loading. Total mass of the model is 800.36 lb.

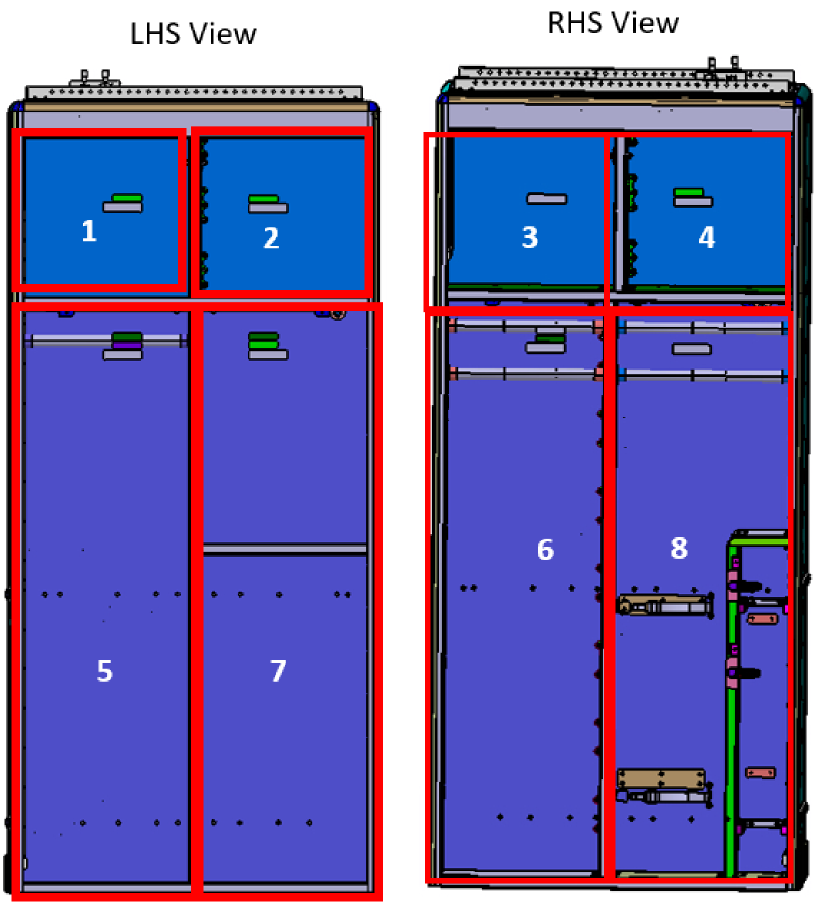


Figure 24 Pressure Zones for "Decompression + 1G Down" Load Case (Doors Hidden For Clarity)

Boundary Conditions

The boundary conditions consist of fixed tie rods and conditions (stiffness) of attachments of Closet to the Seat Tracks.

Information about constrained points location, stiffness and constrained degrees of freedom is provided on Figure 255 and in Table 3. Three groups are created to account for overhead stiffness under different load cases. These stiffness with corresponding load cases are listed in Table and Figure .

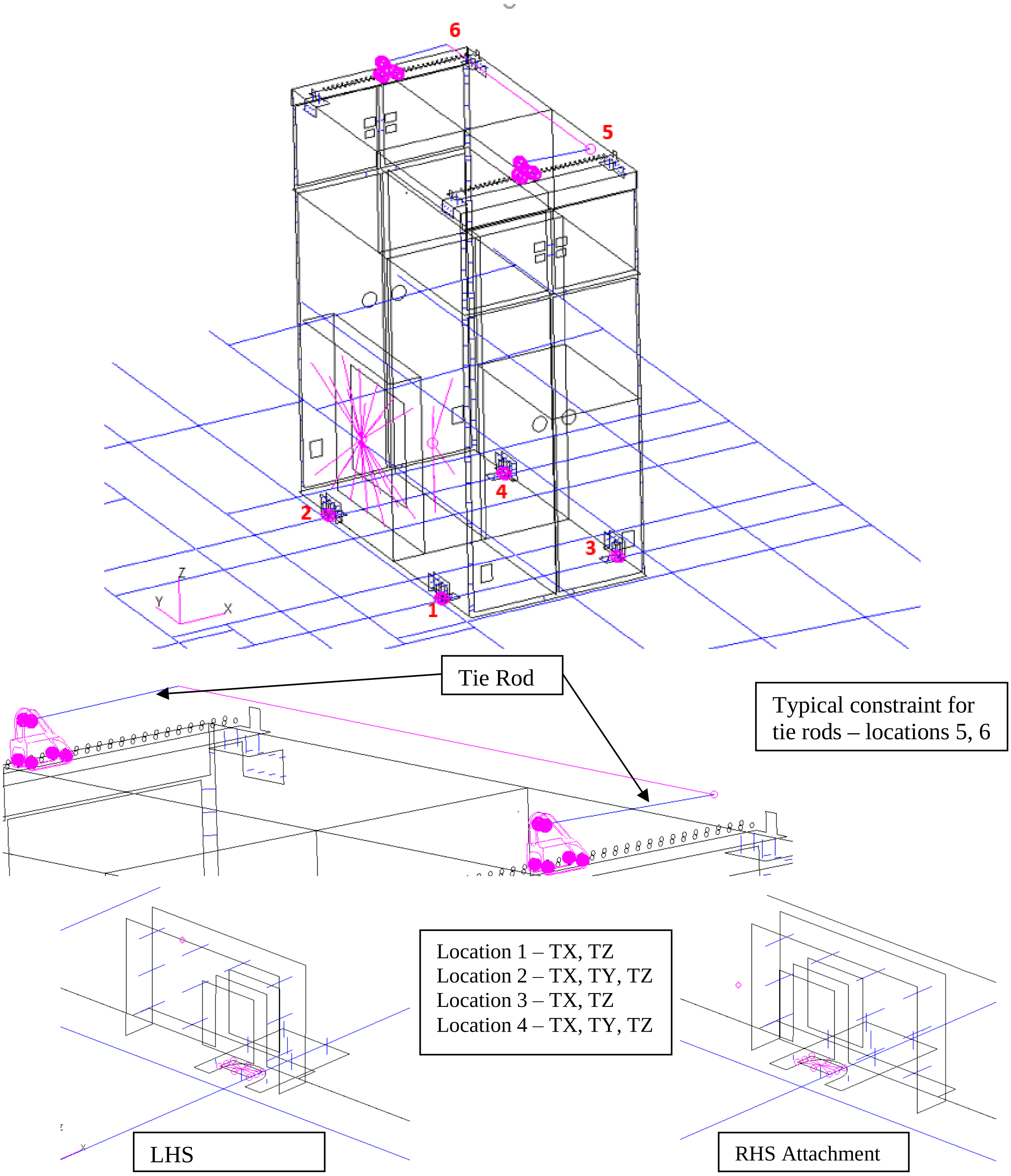


Figure 25 Constraints

Table 13 Constraints

Location	Description	Fixed Degrees of Freedom	Nodes
1	Closet to Seat Track Attachment is performed thru Floor Fittings P/N Support Fitting-1 and Shear Plates P/N Shear Plate	TX, TZ	Node 558519
2		TX, TY, TZ	Node 558520
3		TX, TZ	Node 558522
4		TX, TY, TZ	Node 558521
5	Lattice Rail Attachment Point	TX, TY, TZ	Node 671796
6		TX, TY, TZ	Node 671795

Table 14 Overhead Attachment Stiffness Summary Table

Load Case	Attachment Point 5 Stiffness	Attachment Point 6 Stiffness
FWD/AFT	Kx = 23000 lb/in, Ky =13000 lb/in	Kx = 23000 lb/in, Ky =0 lb/in
Right/Left	Kx = 11000 lb/in, Ky =5000 lb/in	Kx = 11000 lb/in, Ky =0 lb/in
Down/Up	Kx = 0 lb/in, Ky =0 lb/in	Kx = 0 lb/in, Ky =0 lb/in

. FLEX CENTERLINE ZONE

Attachment	Load condition	Stiffness value
Lower Attachments	Fwd/Aft	Kx = Ky = 100K Lb/in Kz = "Low" floor model
	Other	Kx = Ky = 100K Lb/in Kz = "High" floor model
Upper Attachments	Fwd/Aft	Kx = 23K Lb/in Ky = 13K Lb/in Tie-rod: K = 300K Lb/in
	Side	Kx = 11K Lb/in Ky = 5K Lb/in Tie-rod: K = 300K Lb/in
	Up/Down	Kx = Ky = 0 Lb/in Tie-rod: K = 300K Lb/in

Figure 26 Centerline Closet Stiffness Summary

Materials and Properties

The following linear isotropic (Table 15) and composite (Table 16) material properties have been assigned to elements representing the respective structural components. Layers of composite materials are shown in Table 17.

Table 15 Isotropic Properties

Component	Material	Elastic Modulus, E (psi)	Poisson's Ratio, ν	Density, lb/in^3
Support Brackets	7050-T7451	10300000	0.33	0.102
Angles	7075-T6511	10300000	0.33	0.101
Lower Support Fitting	7050-T7451	10300000	0.33	0.102
Shear Plate	7075-T73	10300000	0.33	0.101
Rails	7075-T6511	10300000	0.33	0.101
Tie rods	20204-T42	10500000	0.33	0.1

Table 16 2-D Orthotropic Properties

2D Orthotropic material	Elastic Modulus, E_{11} (psi)	Elastic Modulus, E_{22} (psi)	Poisson's Ratio, ν_{12}	Shear Modulus, G_{12} (psi)	Shear Modulus, G_{23} (psi)	Shear Modulus, G_{13} (psi)
NOMEX	100	100	0.13	100	3700	6417
FIBERGLASS (Facesheet, 2 plies)	3146500	3146500	0.13	680000	100	100

Table 17 Layers

Component	Layer Material	Thickness, in	Orientation, °
All Closet Panels	FIBERGLASS (Skin)	0.022	0
	NOMEX (Core)	0.95	90
	FIBERGLASS (Skin)	0.022	0

FEM Verification

According to Quality Checklist a few checks have been conducted:

- Element normals;
- Duplicates;
- Free edges;
- Element geometry check;
- Thicknesses and offsets;
- Model weight;
- Pressure orientation;
- Convergence ratio.

Closet Panels Analysis

The sandwich honeycomb panels are checked for core crushing, core shear and facesheet flexural strength.

Closet Panel Deflections

In order to determine the critical load case for the Closet Panels, deflections of panels were evaluated. It is assumed, that the load case with maximal deflections is the most critical for the Closet. Maximal deflections for all load cases are presented in Table **18**18 below.

Table 18 Maximal Panel Deflections

Load Case	Deflection	Node
9G Forward·	0.49	18628
1.5G Aft	0.35	285877
6G Down	0.58	61183
3G Up	0.29	64181
3G Left	1.07	314719
3G Right	1.19	320354
1.6G Left + 1.5G Down	0.59	324719
1.6G Right + 1.5G Down	0.65	320355
0.8G Forward + 1.5G Up	0.33	285876
0.5G Forward + 2.4G Up	0.28	285881

0.5G Aft + 2.4G Up	0.23	61183
3.8G Down + 1.5G Forward	0.51	285869
5.6G Down + 0.8G Forward	0.53	61183
7.0G Down + 0.5G Forward	0.67	61183
7.0G Down + 0.5G Aft	0.68	61183
3G Down + 1.5G Aft	0.46	285883
Decompression + 1G Down	1.15	336631

NOTE: Maximal deflection of 3.17 inches found under 9G Forward load case, Node 285873, for closet internal divider Panel-5 (see Figure). Payloads inside of the Closet cause this maximum deflection, located on the free edge of the panel. It does not affect structural integrity and is not a subject for the load share as located inside.

Maximal deflection for Face Outer Panels for Critical Load Case 9G Forward is presented on Figure 27.

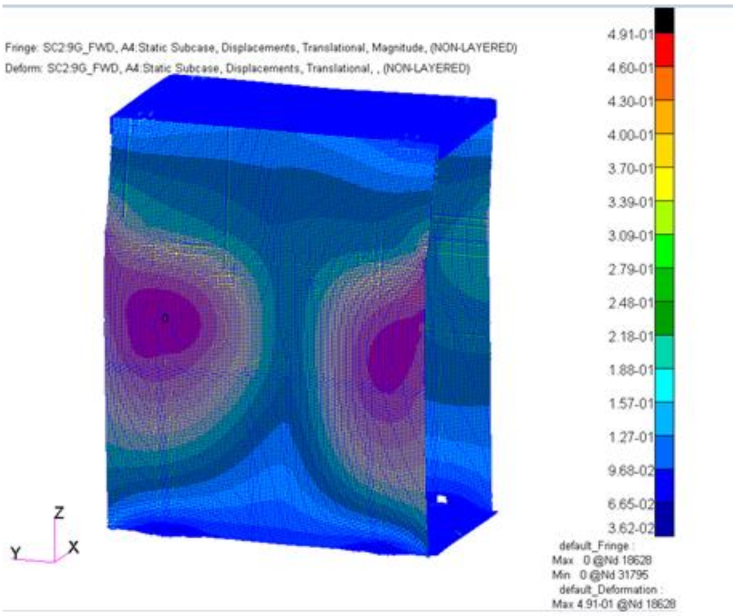


Figure 27 Maximal Face Panel Deformation Under 9G Forward Load Case

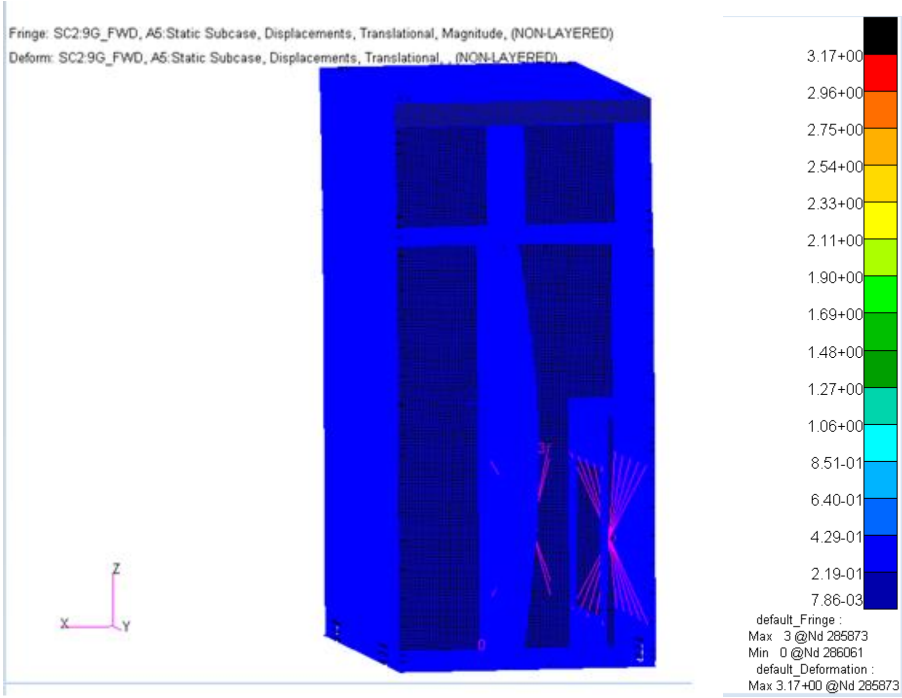


Figure 28 Panel Deformations Under 9G Forward Loads Case

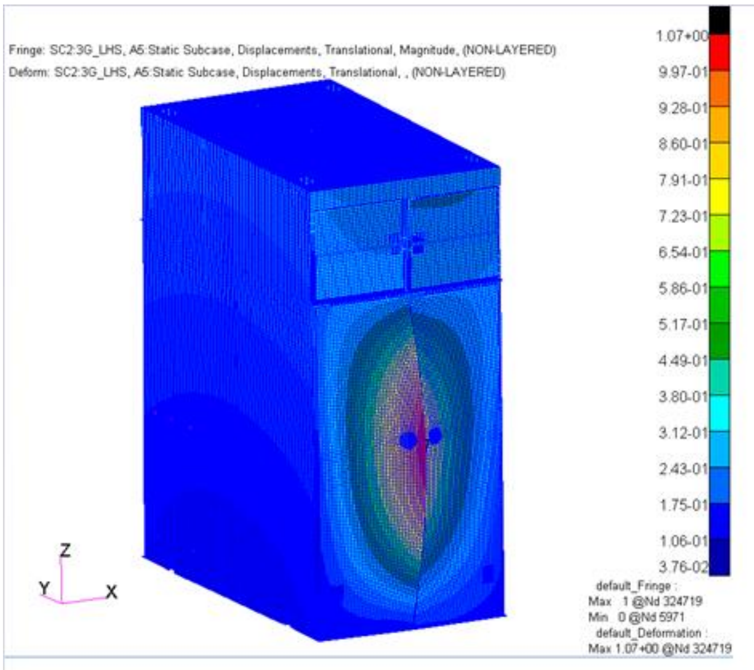


Figure 22 Closet Deformation Under 3G Left Load Case

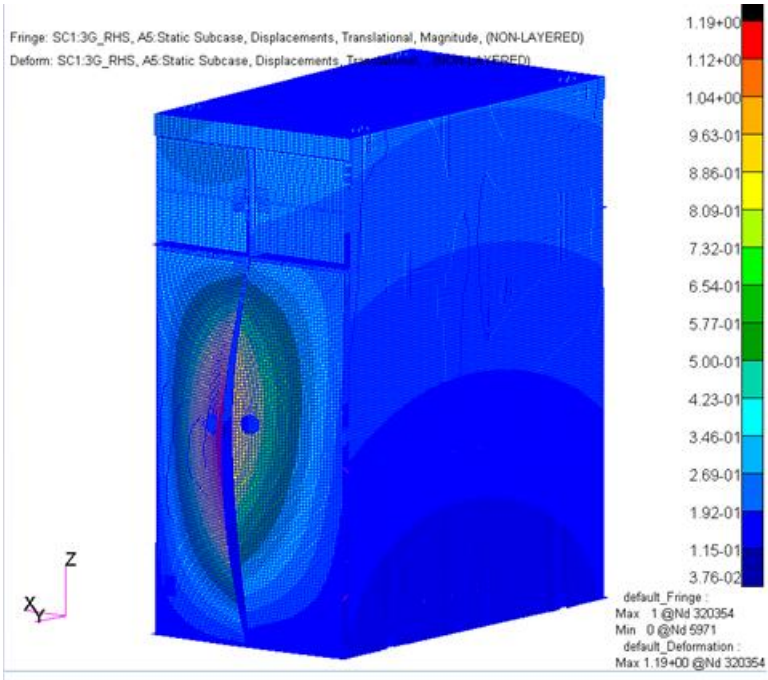


Figure 303 Closet Deformation Under 3G Right Load Case

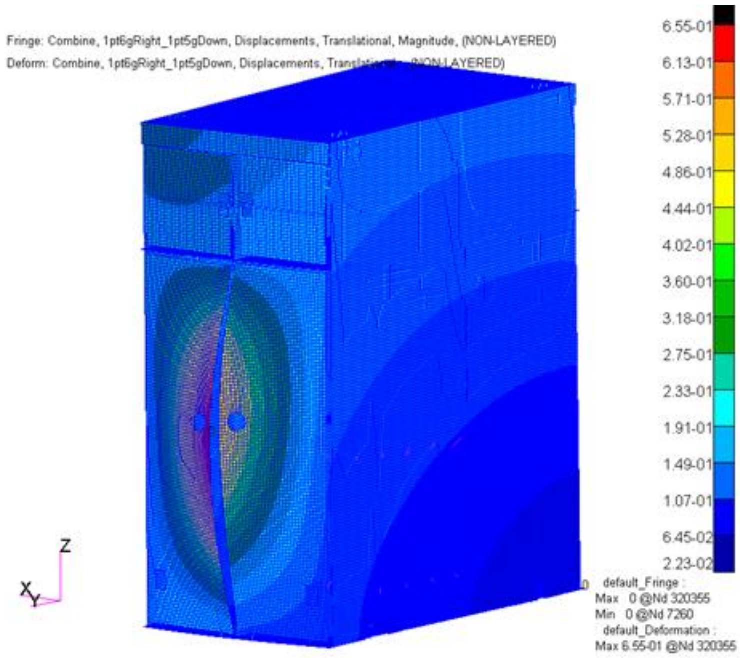


Figure 31 Closet Deformation Under 1.6G Right + 0.5G Down Load Case

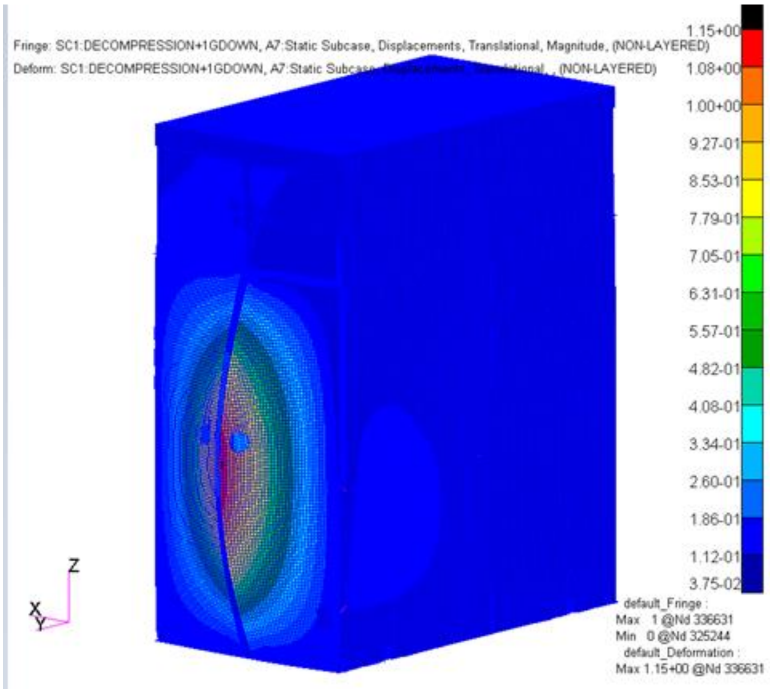


Figure 32 Closet Deformation Under Decompression + 1G Down Load Case

Panels Analysis

The analysis of the Panels is performed using approved Panel Analysis Tool in Patran. This tool calculates Margins of Safety for all elements separately. Internal loads for Margins of Safety calculation are obtained from FEM analysis. The equations used are per Standard Method for analyzing Honeycomb Sandwich Panels. Per Patran tool guidance sandwich panels are modeled as a 3 plies material (facesheet – core – facesheet). Stresses are obtained from FEM analysis file.

The analysis is performed for all panels and all load cases critical load case for both core and Facesheet separately.

Minimal Margins of Safety Summary for most critical load cases is presented in Table **191**19. Locations with minimal Core and Facesheet values are presented on **Table 191**19.

Table 191 Minimal Margins of Safety for Panels

		Failure Mode	9G FWD	6G Down	3G Right	Decompression +1 G Down
Panel-1	Facesheet	Combined	2.24	2.71	1.68	4.98
	Core	Combined	0.53	High	High	0.42

Panel-2	Facesheet	Combined	2.78	2.00	1.30	High
	Core	Combined	**0.40**	High	High	0.85
Panel-3	Facesheet	Combined	1.28	High	High	2.65
	Core	Combined	0.77	3.37	High	4.15
Panel-4	Facesheet	Combined	0.71	High	High	High
	Core	Combined	1.87	High	High	High
Panel-5	Facesheet	Combined	1.35	High	High	High
	Core	Combined	**0.32**	High	High	High
Panel-6	Facesheet	Combined	High	High	High	High
	Core	Combined	2.25	High	High	High
Panel-7	Facesheet	Combined	1.37	High	High	High
	Core	Combined	High	High	High	High
Panel-8	Facesheet	Combined	1.98	1.26	4.22	2.12
	Core	Combined	High	3.80	High	4.10
Panel-9	Facesheet	Combined	3.63	High	High	High
	Core	Combine	2.04	High	High	High

		d				
Panel-10	Facesheet	Combined	High	High	High	High
	Core	Combined	2.57	High	High	4.97
Panel-11	Facesheet	Combined	High	High	High	High
	Core	Combined	4.24	High	High	4.05
Panel-12	Facesheet	Combined	4.90	High	High	High
	Core	Combined	High	High	High	High
Panel-13	Facesheet	Combined	**0.27**	High	High	High
	Core	Combined	High	High	High	High
Panel-14	Facesheet	Combined	3.74	High	2.73	2.29
	Core	Combined	High	High	1.07	1.01
Panel-15	Facesheet	Combined	High	High	3.68	1.75
	Core	Combined	High	High	1.37	0.68
Panel-16	Facesheet	Combined	High	High	High	High
	Core	Combined	High	High	0.72	3.92
Panel-17	Facesheet	Combined	High	High	High	High

	Core	Combined	High	High	High	High

Note: Values marked orange are minimal Margins of Safety for core and facesheet against all panels. Excessive peak stresses around connection bush-elements are omitted and hand analysis calculations are provided in particular analysis sections.

Margins of Safety are calculated with equations using a combination of tension, compression and shear stress ratio.

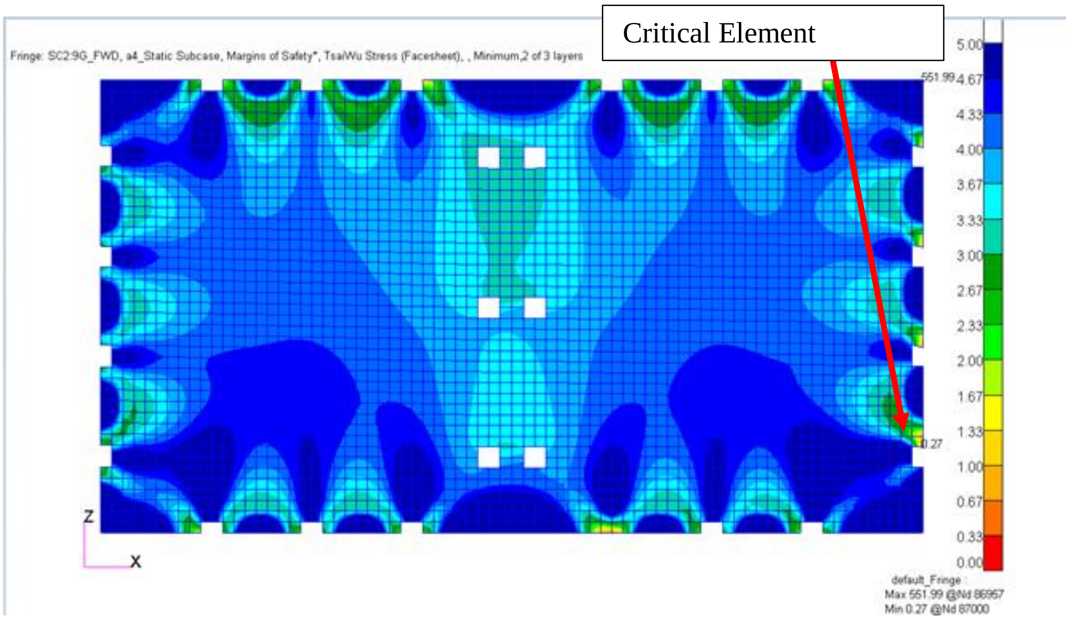


Figure 33 Facesheet Minimal Margins of Safety Location (Panel P/N Panel-13, 9G Forward Load Case)

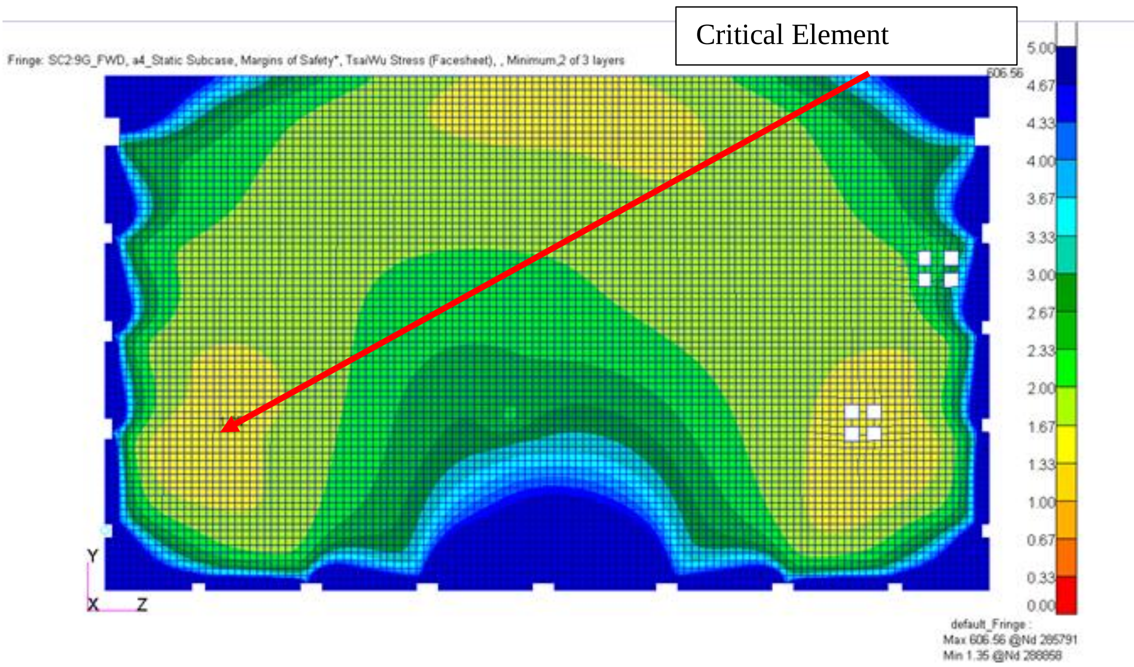


Figure 4 Core Margins of Safety (9G Forward Load Case, One Row of Elements Removed)

Panel Analysis at Bonded Core Splice

There is a Bonded Core splice on FWD/AFT Panels. Analysis of the bonded core is performed in the same manner as for other parts of panels. The only difference between these zones is in Core and Facesheet Allowables (see **Table** 3). Minimum Margins of Safety Summary for Bonded Core Splice for Core and Facesheet are presented in **Table** . Locations of Elements with Minimal Margins of Safety for Facesheet and Core and presented on Figure and Figure 365 correspondently. Critical Load Case is 9G Forward.

Table 20 Minimum Margin of Safety Summary for Panels at Bonded Core Splice

	Failure Mode	Panel-1		Panel-2	
		Core	Facesheet	Core	Facesheet
9G Forward	Combined	0.62	3.17	2.56	4.73
1.5G Forward	Combined	High	High	High	High
6G Down	Combined	High	High	High	High
3G Up	Combined	High	High	High	High
3G Left	Combined	High	High	High	High
3G Right	Combined	High	High	High	High
1.6G Left + 1.5G Down	Combined	High	High	High	High
1.6G Right + 1.5G Down	Combined	High	High	High	High
0.8G Forward + 1.5G Up	Combined	High	High	High	High
0.5G Forward + 2.4G Up	Combined	High	High	High	High
0.5G Aft + 2.4G Up	Combined	High	High	High	High
3.8G Down + 1.5G Forward	Combined	High	High	High	High
5.6G Down + 0.8G Forward	Combined	High	High	High	High
7.0G Down + 0.5G	Combined	High	High	High	High

Forward					
7.0G Down + 0.5G Aft	Combined	High	High	High	High
3G Down + 1.5G Aft	Combined	High	High	High	High
Decompression + 1G Down	Combined	High	High	High	High

MS "High" means > 5

Note: Margins of Safety are calculated with equations using a combination of tension, compression and shear stress ratios.

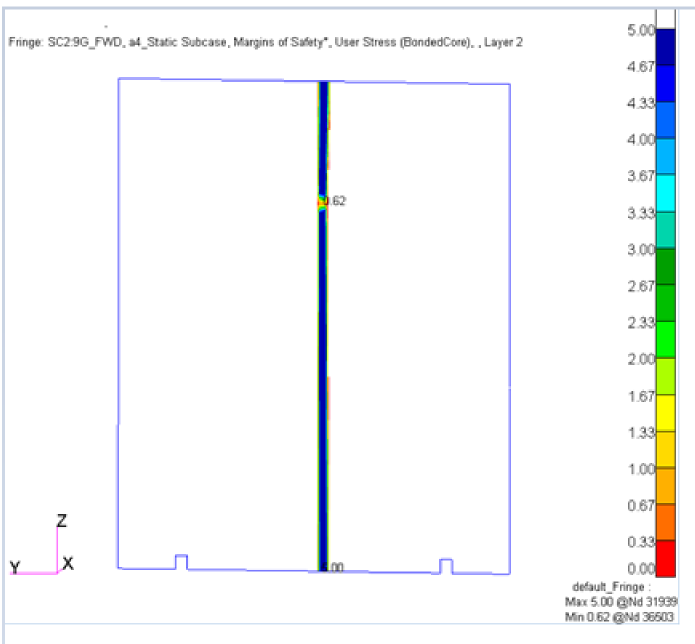


Figure 35 Element with Minimal Facesheet Margins of Safety for Bonded Core Splice (9G Forward Load Case)

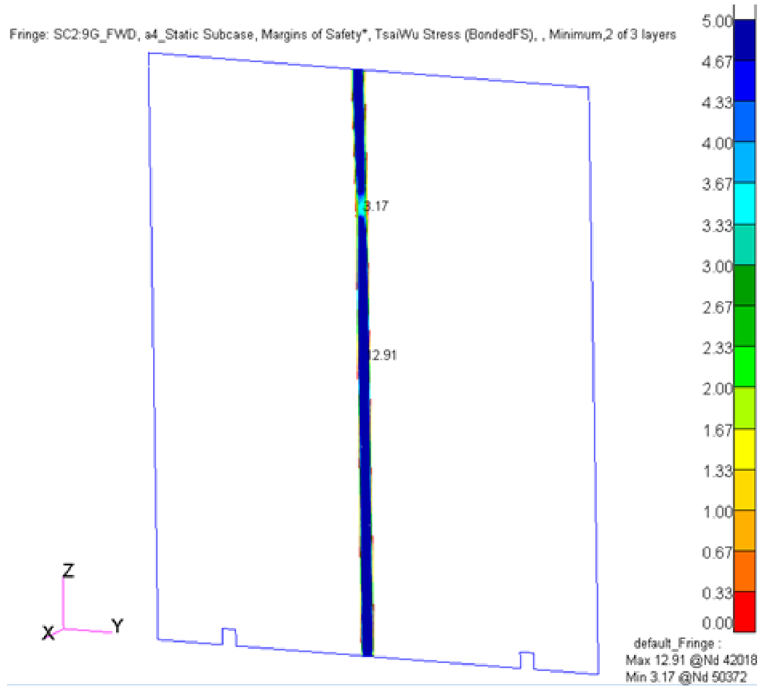


Figure 365 Element with Minimal Core Margins of Safety for Bonded Core Splice (9G Forward Load Case)

Doors Analysis

There are 4 doors used in the Centerline Closet as shown on Figure 37.

For substantiation of Doors Panel-14 previously approved method is used.

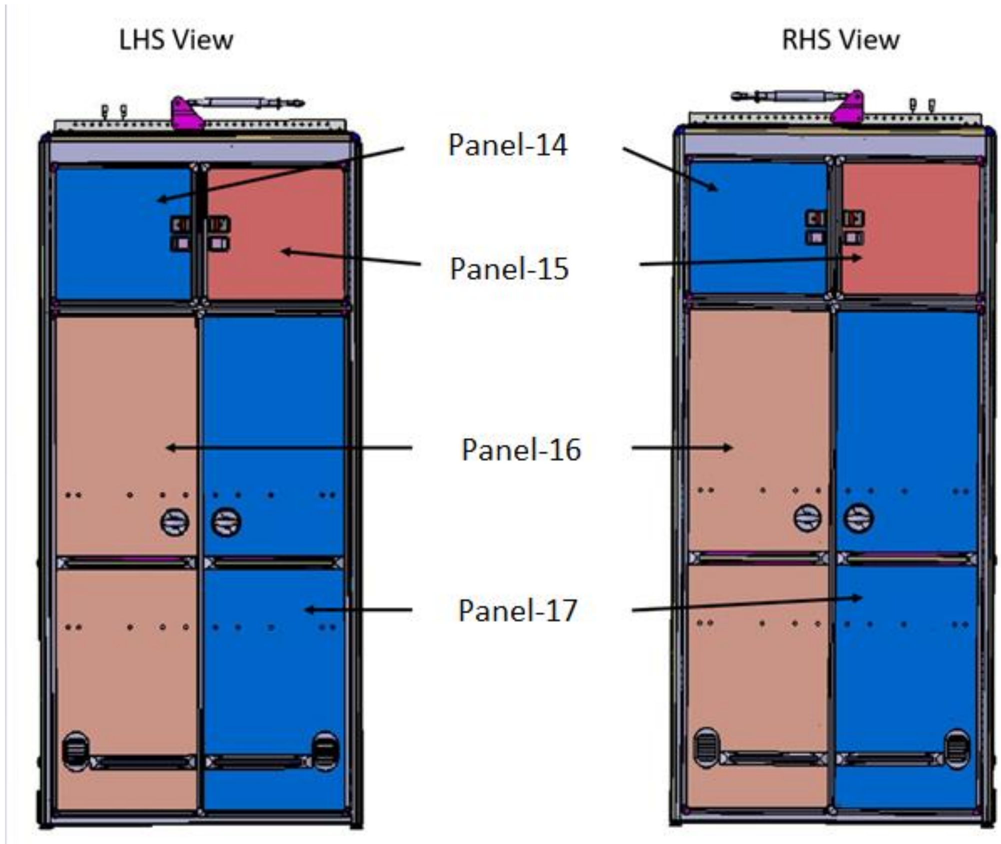


Figure 37 Door Arrangement

All the doors are made from 1.00” fiberglass honeycomb panel with hinges and dead bolt rotary latches installed on the Closet. All the panels of the doors are modeled in the FEM of the Closet. Their strength has been checked in the Panel Strength Analysis Section.

Main Doors Latch

Dead bolt rotary latch is used for Main Doors.

Its design value Psu =400 lb.

Per the results of FEA, maximum load under 3G Right Load case is 103.73 lb at the upper latch of the RH Aft main door.

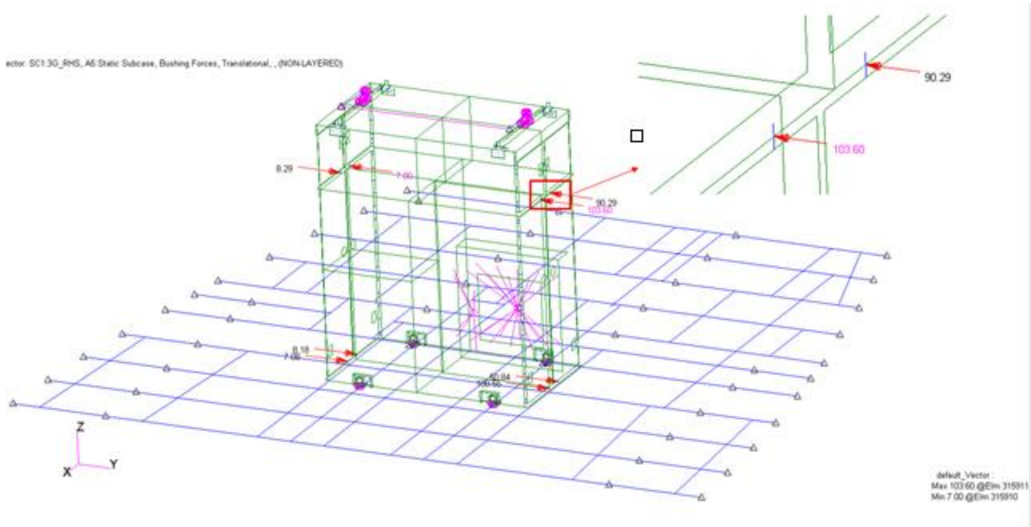


Figure 386 Latch Maximum Load Location (3G Right Load Case)

Maximum acting shear load:

Ps = 103.60 lb (see Figure 386)

Margin of Safety with 1.33 factor:

MS = Psu/(1.33·Ps) - 1= 400 / (1.33 · 103.60) - 1 = 1.90=High (3G Right Load Case)

Upper Door Latch

Slam latch is used for all the upper doors.

Its design value Psu =100 lb.

Content weight of all the Upper Sections per Weight and C.G. List (see Table **8**8) is 25 lb.

Latch load under 3G Side Load Cases:

Ps = 3·25/2 = 37.5 lb

Margin of Safety with 1.33 factor:

MS = Psu / (1.33·Ps) – 1 = 100 / (1.33·37.5) - 1 = 1.00 (3G Side Load Case)

Tab-Slots

Most of the Closet panels are joined together with tab and slot joints. Two types of tab-slots are used to join Closet Panels – Blind Rabbet and Mortise & Tenon joints. The strength of the joints is analyzed using SmartBush tool in MSC Patran. This tool compares acting loads in Bush Elements representing Tab-Slot Joint with allowable forces and presented on **Figure** . Minimal Tab-slot Margin of Safety is found for Forward Face Panel P/N Panel-2 to Floor Panel P/N Panel-3 Blind Rabbet joint under 9G Forward Load Case. Critical Margins of Safety beyond all Tab-Slot joints are presented in **Table** . Critical Tab-Slot Margin of Safety found under 9G Forward Load Case is presented on **Figure 39**.

Table 21 Minimal Tab-Slot Margin of Safety Summary

Load Case	Minimal Tab-Slot M.S.
9G FWD	**0.18**
1.5G Aft	High
3G Up	High
6G Down	High
3G Right	High
3G Left	High
1.6G Left+1.5G Down	High
1.6G Right + 1.5G Down	High
1.5G Up + 0.8G FWD	High
2.4G Up + 0.5G FWD	High
2.4G Up + 0.5G Aft	High
3.8G Down +1.5G FWD	High
5.6G Down +0.8G FWD	High
7.0G Down +0.5G FWD	High
7.0G Down + 0.5G Aft	High
3G Down + 1.5G Aft	High
Decompression +1 G Down	0.84

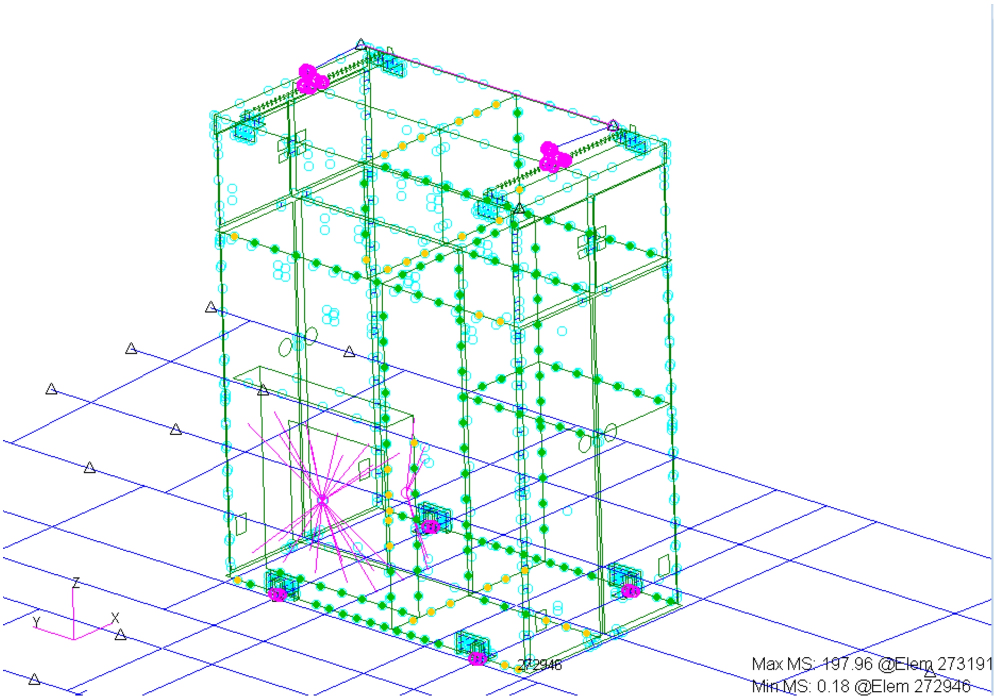


Figure 39 Critical Blind Rabbet Tab-Slot Location (9G Forward Load Case)

Dogbones

Some panels are joined together with dog bone joints as shown on **Figure 7** and **Figure 8**. The strength of these dogbone joints is checked by the IRC standard dogbone analysis template which uses loads resulted from Finite-Element analysis, dogbone geometry, material and panel inserts allowables to calculate Margin of Safety for both dogbones and inserts. Four types of Dogbones used in analysis are presented on **Figure** 5.

Dogbones are separated by groups depending on joined panels. Each group is analyzed separately for all load cases. Analysis for critical dogbone with minimal insert Margin of Safety is presented on **Figure 9**, **Figure 10**.

The minimum Margins of Safety for critical dogbone and insert of each group are listed in **Table 22**.

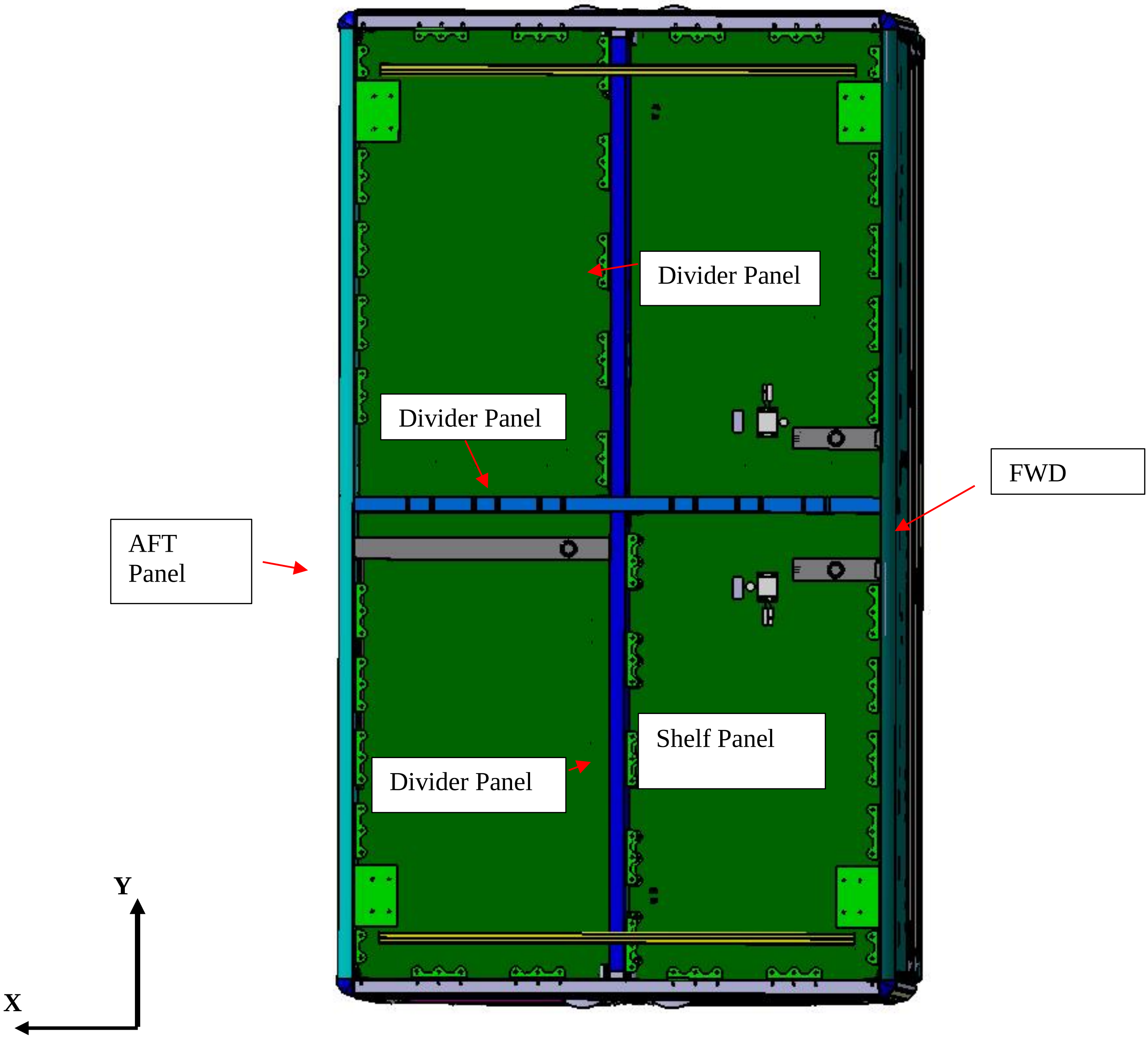


Figure 7 Dogbones Location (View from Above, Ceiling Panel Hidden for Clarity)

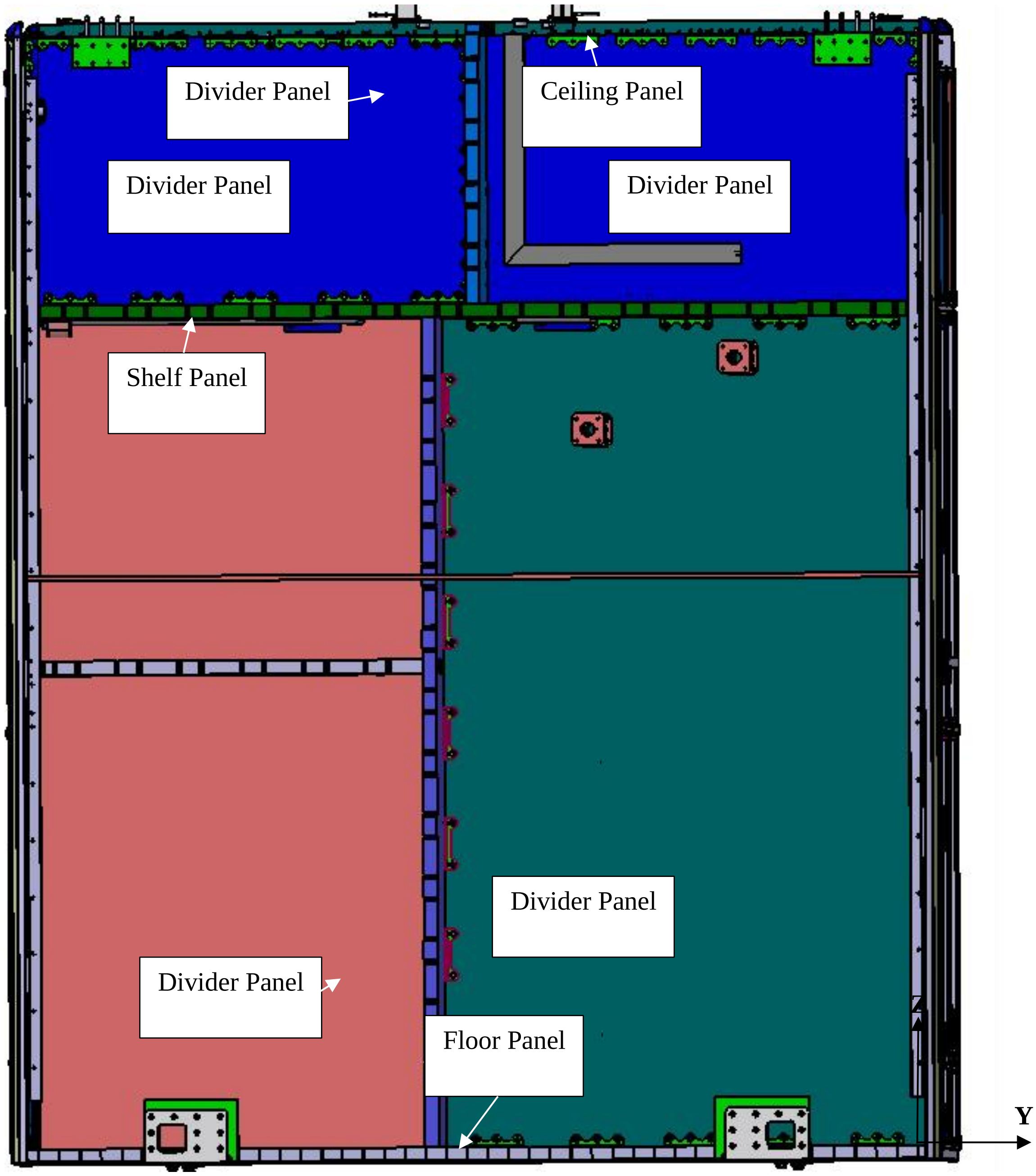


Figure 8 Dogbones Location (View from AFT, AFT Panel Hidden for Clarity)

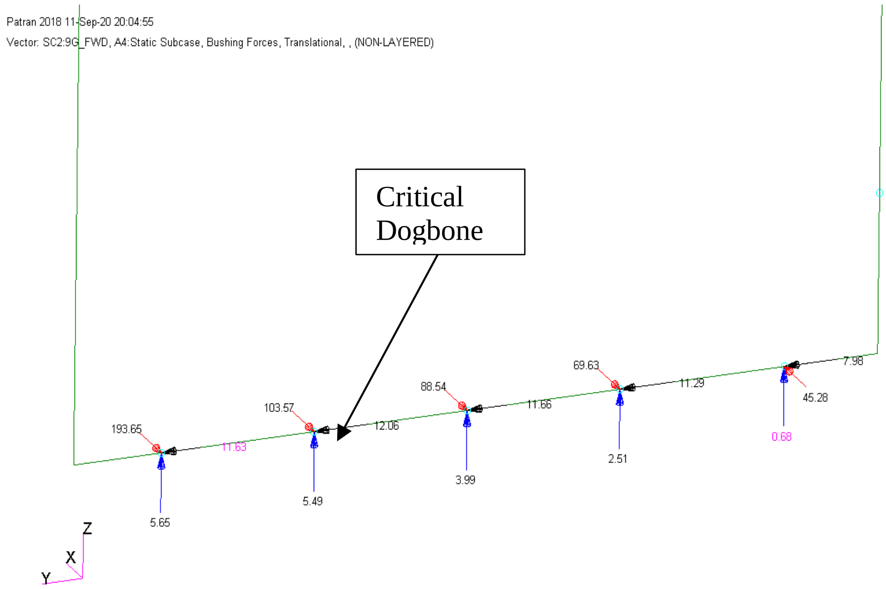


Figure 9 Loads For Critical Dogbone (Divider Panel to Floor Panel, 9G Forward Load Case)

STANDARD SHEAR-TIE FITTING (DOGBONE) ANALYSIS

Join with windscreen panel and aft floor panel

Applied to: Dog bone

1. Applied Loads for Dogbone

[V is parallel to pnl edge; P1 is normal to PNL1; P2 is normal to PNL2.]

	V	P1	P2	
Applied Loads on PNL1	12	194	6	9G Fwd Case, See Figure 1 Pnl 1-1" fg Divider Panel
Load Case (Flight / Emerg. Land = F / E)	E			Pnl 2-1" fg Floor Panel

(effect on Metal part allowable P-load only)

2. Dogbone type (see General Info):

Legs per side (2 or 3): n	3
Dist between side inserts (3" or 6"): d	3

3. Allowable Loads for Metal Part

Ref. [1], [1a], [2], [3]

Mat'l properties (from [2], [3]):	Ftu (ksi	Fty	Fcy	E (Msi)	B10	m
6013-T6 (bare sheet)	52	46	48	10,1	0,0530	0,80

Dimensions:	thk
	0,05

Intermediate results:	Fcc	C_u
	46,5	0,0711

Dogbone Allowables [1], [1a]:	V	P
(P - only for Flight Load Cases)	1435	1468

4. Allowable Loads for inserts

Vi,1 ./ Vi,2 - insert shear allowables (away from / toward panel edge). Pi - insert tension allowable.
ED - edge distance. NFE - No foam edge. UBFE - Unbonded foam edge.

		Ins. Allowable [4], [5]			
PNL	Insert type / panel details	Vi,1	Vi,2	Pi	
1	Insert-1 / 1.00"" 2 Ply FB Skin, 3# core	200	200	238	ED=0.5,Nomex,
2	Insert-2 / 1.00"" 2 Ply FB Skin, 3# core	375	375	238	ED=1.5, Nomex,

5. Check Metal Part

Rt1	Rt2	Rs	Rt	MS
0,132	0,004	0,008	0,136	>3

6. Check Inserts

Moment M = x1*P1 - x2*P2 (xi=0.55" or c)	103,4	(a = 0,359)	For M, x1=0.55 for P1>0 and x1=c for P1<0
Reaction N1 = 0.5*M / y1 (y1=a or b)	144,0	(b = 0,385)	x2=0.55 for P2>0 and x2=c for P2<0
Reaction N2 = 0.5*M / y2 (y2=a or b)	134,3	(c = 0,165)	For N1, y1=a for M>0 and y1=b for M<0
			For N2, y2=b for M>0 and y2=a for M<0

[Vti-shear load along the pnl edge; Vni-shear load normal to pnl edge.]

	Effect of	Vti	Vni	Pi	Rs	Rt	MS	
PNL 1	V load	4	2	0				Vti = V/n; Vni = 0.55*V/d
	P1 and P2 loads	0	2	113				Vni = P2/n; Pi = (N1+P1)/n
	SUM	4	4	113	0,028	0,473	1,00	
PNL 2	V load	4	2	0				Vti = V/n; Vni = 0.55*V/d
	P1 and P2 loads	0	65	47				Vni = P1/n; Pi = (N2+P2)/n
	SUM	4	67	47	0,178	0,196	1,67	

For (+) sign Vni is acting toward panel edge

Figure 10 Margin of Safety Calculation for Critical Insert / Dogbone (9G Forward Load Case)

Table 22 Minimum Margin of Safety Summary for Dogbones

Dog Bone	Insert Type	Panel #1	Panel #2	Load Case	Insert Min MS	Dogbone Min MS
Dogbone-1	INSERT-1	AFT Panel P/N Panel-1	Ceiling Panel P/N Panel-4	9G FWD	2.58	High
Dogbone-2	INSERT-1	AFT Panel P/N Panel-1	Ceiling Panel P/N Panel-4	9G FWD	High	High
Dogbone-1	INSERT-1	FWD Panel P/N Panel-2	Divider Panel P/N Panel-10	9G FWD	1.84	High
Dogbone-1	INSERT-1	FWD Panel P/N Panel-2	Ceiling Panel P/N Panel-4	9G FWD	High	High
Dogbone-2	INSERT-1	FWD Panel P/N Panel-2	Ceiling Panel P/N Panel-4	9G FWD	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-6	Ceiling Panel P/N Panel-4	9G FWD	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-6	Divider Panel P/N Panel-13	7.0G Down + 0.5G Aft	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-6	Shelf Panel P/N Panel-8	7.0G Down + 0.5G Aft	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-11	Ceiling Panel P/N Panel-4	7.0G Down + 0.5G FWD	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-11	Divider Panel P/N Panel-13	7.0G Down + 0.5G FWD	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-11	Shelf Panel P/N Panel-8	7.0G Down + 0.5G Aft	High	High
Dogbone-1	INSERT-1	Divider Panel P/N Panel-5	Shelf Panel P/N Panel-8	9G FWD	1.12	High
Dogbone-3	INSERT-1	Divider Panel	Divider Panel	9G FWD	1.10	High

Dogbone-1	INSERT-1	P/N Panel-5 Divider Panel P/N Panel-5	P/N Panel-7 Floor Panel P/N Panel-3	9G FWD	1.00	High

Note: All Margins of Safety > 3 are marked as “High”.

Inserts

Three types of Inserts are used to attach Fittings and Angles to the Panels. They are as follows:

- INSERT-4 THRU inserts are used in joint with Floor Fittings P/N Support Fitting-1B.
- INSERT-2 inserts are used in joints of Floor Panel with Shear Plates and Upper Angle Bracket P/N Angle Bracket with FWD/AFT Face Panels.
- INSERT-3THRU inserts are used to attach Angle Bracket P/N Angle Bracket to Ceiling Panel.

Minimal Margin of Safety Summary for Inserts is presented in **Table 242**. Analysis for all types of inserts is presented below for Critical Insert of each type.

INSERT-4

Critical INSERT-4 insert is found under 9G Forward Load Case at the attachment of left Floor Fitting Support Fitting-1B to the Aft Face Panel. The Load acting on critical insert is presented on **Figure 11**.

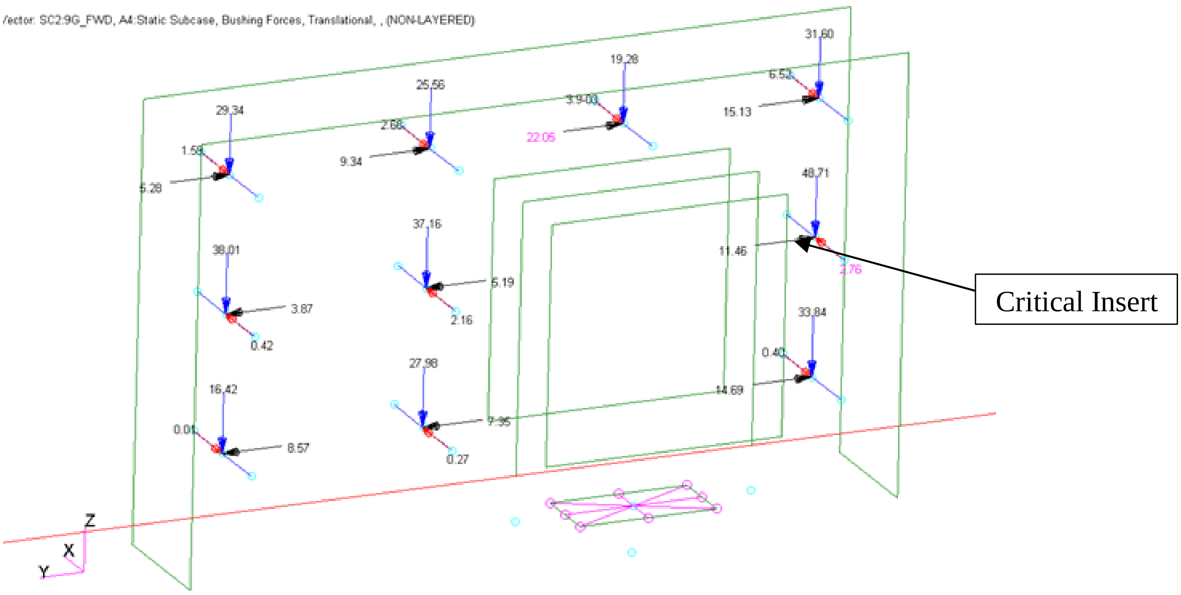


Figure 11 Critical INSERT-4 Insert Load (9G Forward Load Case)

Allowable for INSERT-4:

Allowable Tension, ED = 0.5: Ptu = 318 lb

Allowable Shear, ED = 0.5: Psu = 245 lb

Acting Loads:

Tension: Pt = 2.76 lb

Shear: Ps = ((48.71) ^2 + (11.46) ^ 2) ^0.5=50.04 lb

Reserve Factor:

Tension: Rt = Pt / Ptu = 2.76 / 318 = 0.01

Shear: Rs = Ps / Psu = 50.04 / 245 = 0.20

Margin of Safety with 1.33 fitting factor:

MS = 1/ (1.15·(Rs+Rt)) - 1 = 1/ (1.15·(0.01 + 0.20)) – 1 = 3.08 (9G Forward Load Case)

INSERT-2

Critical INSERT-2 insert is found under 9G Forward Load Case at the attachment of Shear Plate to Floor Panel. The Load acting on critical insert is presented on **Figure 12**.

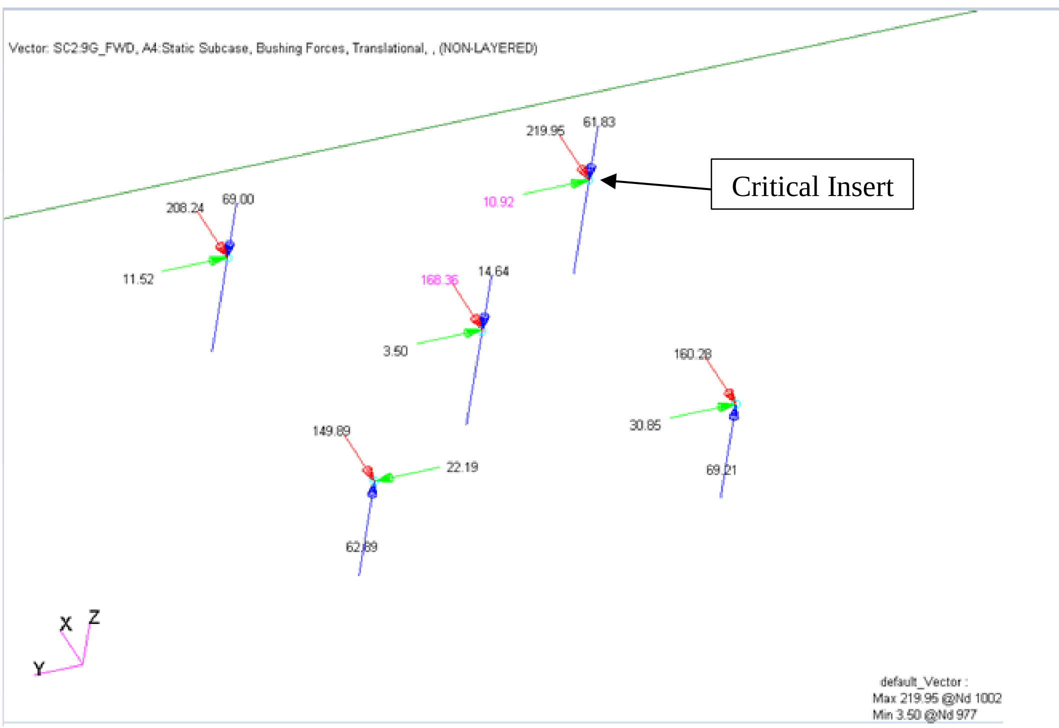


Figure 12 Critical INSERT-2 Insert Load (9G Forward Load Case)

Allowable for INSERT-1 in 18 Grade Foam:

Allowable Tension: Ptu = 266 lb

Allowable Shear: Psu = 325 lb

Acting Loads:

Tension: Pt = 61.83 lb

Shear: Ps = (219.95^2+10.92^2) ^0.5=220 lb

Reserve Factor:

Tension: Rt = Pt / Ptu = 62 / 266 = 0.23

Shear: Rs = Ps / Psu = 220 / 325 = 0.68

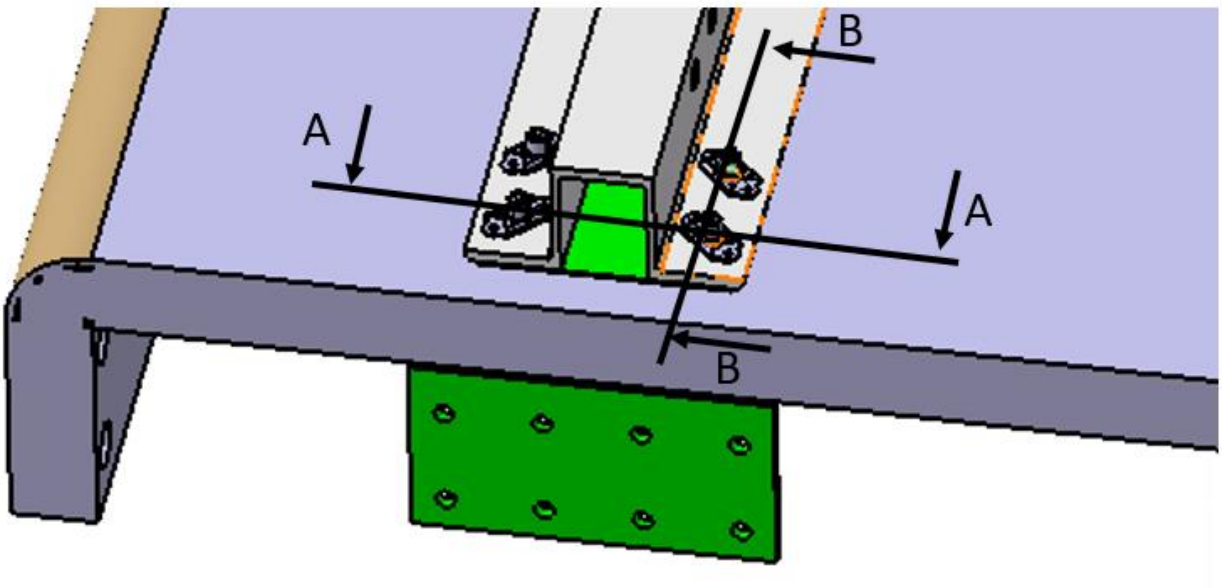
Margin of Safety with 1.15 fitting factor:

MS = 1/ (Rs+Rt) – 1 = 1/ (0.23 + 0.68) – 1 = 0.10 (9G Forward Load Case)

INSERT-3

INSERT-3 are thrue inserts in stack up "Rail Flange-Panel-Angle" (see **Figure 13**), therefore only shear loads are taken for analysis. Tension load of the joint will be carried by fastener and metal flanges and there is no insert pull through check is applicable.

Critical INSERT-3insert is found under 9G Forward Load Case at the attachment of Angle Bracket P/N Angle Bracket to the Ceiling Panel. The Load acting on critical insert is presented on **Figure 14**.



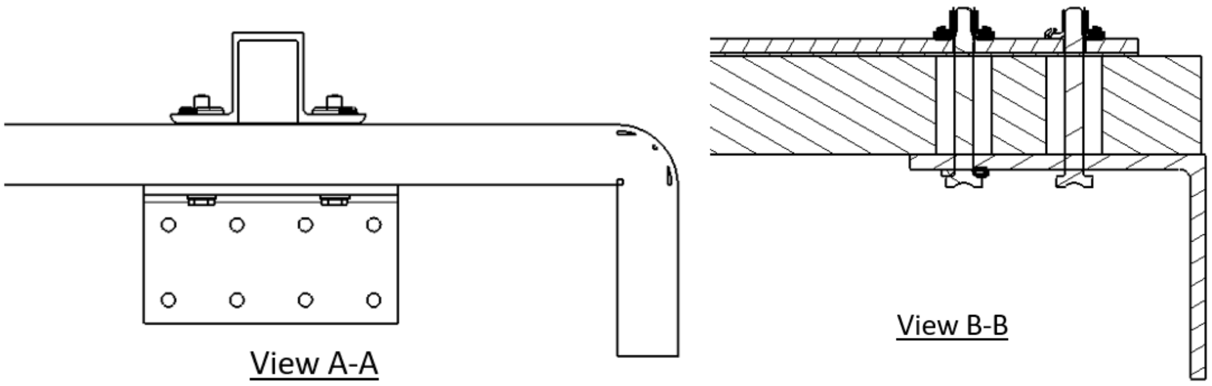


Figure 13 Rail Flange – Ceiling Panel – Angle Joint Geometry

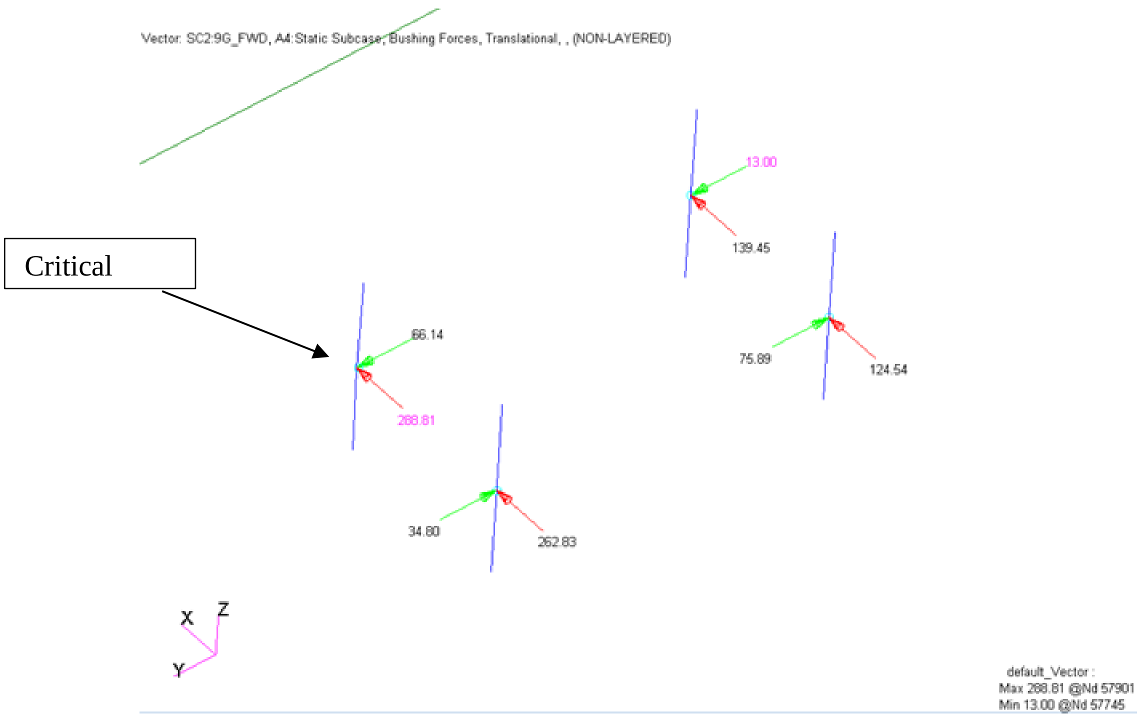


Figure 14 Critical INSERT-3 Load (9G Forward Load Case)

Allowable for INSERT-3 in 18 Grade Foam:

Allowable Tension, ED = 0.5: Ptu = 449 lb

Allowable Shear, ED = 0.5: Psu = 385 lb

Acting Loads:

Tension (Pull through): Pt = 0 lb

Shear: Ps = ((66.14) ^2 + (288.81) ^ 2) ^0.5=296 lb

Reserve Factor:

Tension: Rt = Pt / Ptu = 0 / 449 = 0

Shear: Rs = Ps / Psu = 296 / 385 = 0.77

Margin of Safety with 1.15 fitting factor:

MS = 1/ (1.15·(Rt+Rs)) - 1 = 1/ (1.15·(0 + 0.77)) -1 = 0.13 (9G Forward Load Case)

Table 242 Inserts Margins of Safety Summary

Inserts	Part #1	Part #2	Load Case	Failure mode	Min.MS
INSERT-4	Aft Panel RH	Floor fitting	9.0 G FWD	Insert shear & tension	3.08
INSERT-4	Fwd Panel RH	Floor fitting	9.0 G FWD	Insert shear & tension	3.41
INSERT-1	Floor Panel RH	Shear Plate	9.0 G FWD	Insert shear & tension	0.10
INSERT-1	Aft Panel RH	Upper Bracket	9.0 G FWD	Insert shear & tension	2.10
INSERT-1	Fwd Panel RH	Upper Bracket	9.0 G FWD	Insert shear & tension	0.35
INSERT-3	Ceiling Panel RH	Upper Bracket	9.0 G FWD	Insert shear	0.13

Angle Bracket

Angle Brackets Angle Bracket are used to attach FWD/AFT Face Panels with Ceiling Panel. Brackets are Extruded Profile (see **Figure 13**) from 7075-T6511 Aluminum. Material Properties are as follows:

Ftu = 79000 psi

Fty = 70000 psi

Fsu = 44000 psi

Fbru = 105000 psi

Maximal stress found in Bracket under 9G Forward Load Case is 10542 psi as shown below.

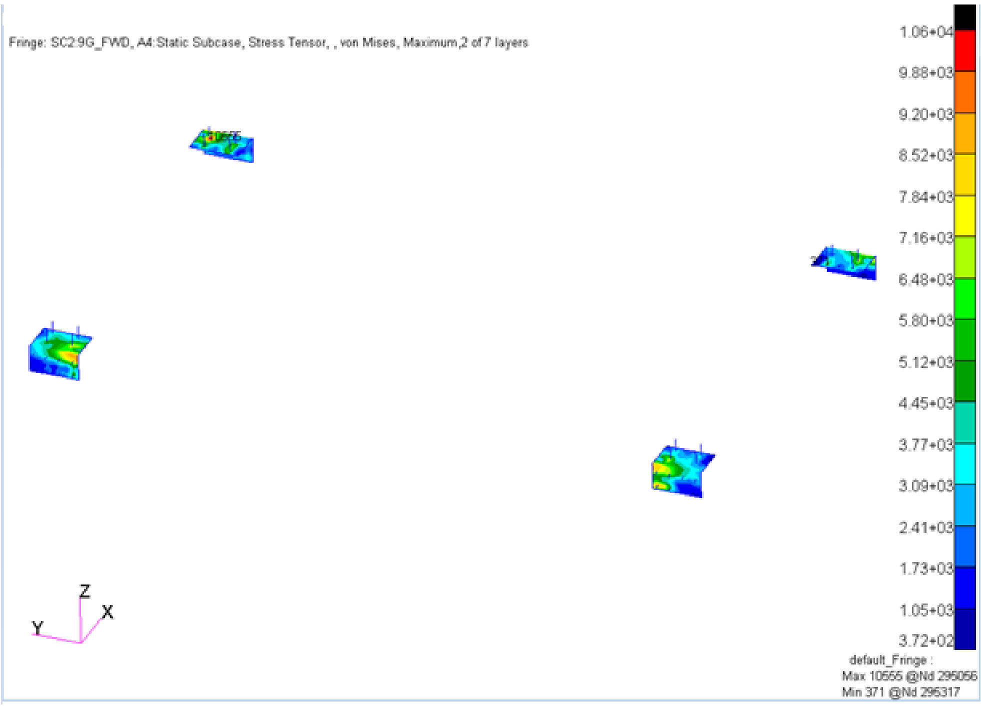


Figure 15 Stresses in Angle Bracket Angle Bracket Under Critical 9G Forward Load Case

Maximal acting von Mises stresses:

ft = 10555 psi

Allowable tension ultimate stress:

Ftu = 79000 psi

Margin of Safety with 1.15 fitting factor:

MS = Ftu / 1.15·ft = 79000 / (1.15· 10555) -1 =5.50   (9G Forward Load Case)

Bearing check:

Maximal Bearing Load

$Pbr = \sqrt{Px^2 + Py^2} = \sqrt{154.29^2 + 15.13^2} = 155.03$ lb

Bolt Diameter (BOLT-3):

D = 0.19 in

Angle Thickness:

t= 0.156 in

Bearing allowable

Pbru =Fbru·D·t = 105000·0.19·0.156= 3112.2 lb

Margin of Safety with 1.15 fitting Factor:

MS = Pbru /(1.15·Pbr) - 1 = 3112.2 / (1.15·155.03) - 1 = 16.45 = High (9G Forward Load Case)

Floor Fitting Support Fitting-1

Floor Fitting Support Fitting-1 is used in four places to attach Centerline Closet to the seat tracks. Critical load case found during analysis is 3G RHS. Fitting is made of Aluminum Alloy 7050-T7451 1.5 inches thick Plate. Material allowables are as follows:

Ftu= 76000 psi,

Fty = 66000 psi

Fsu = 43000 psi

Fbru = 99000 psi for e/D =1.5

Maximal Stresses acting on Floor Fitting Support Fitting-1 are presented on **Figure 16**.

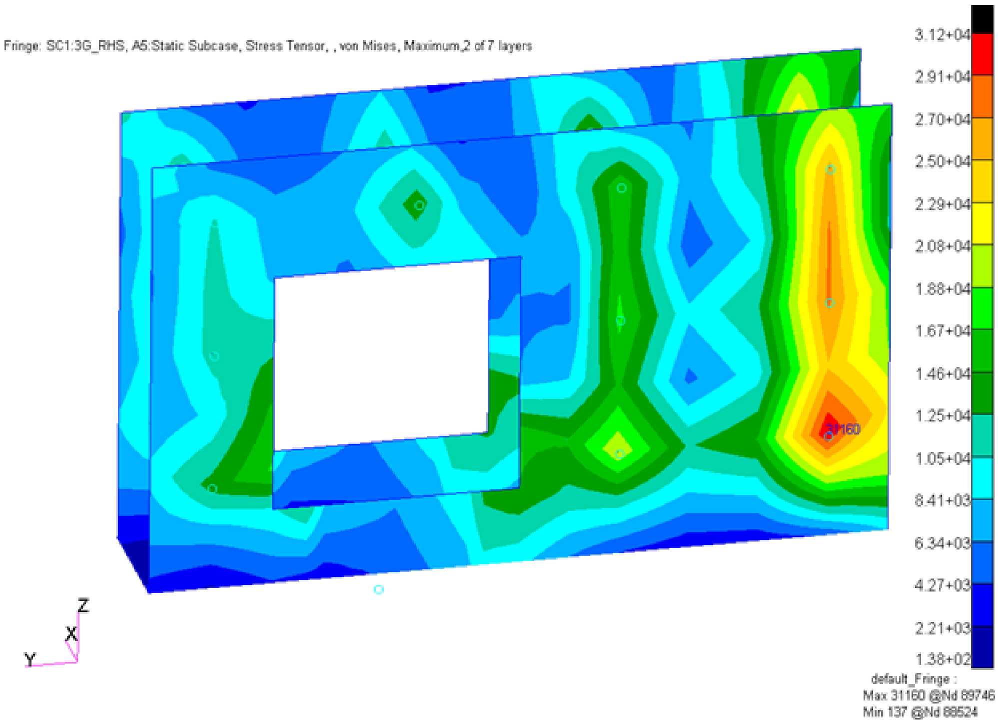


Figure 16 Maximal Von Mises Stresses Acting on Floor Fitting - Support Fitting-1

Max stress in Floor Fitting:

ft = 31160 psi (see **Figure 16**)

Margin of Safety with 1.33 tear and Wear factor:

MS= Ftu / (1.33·ft) = 76000 / (1.33· 31160) -1 = 0.83 (3G RHS Load Case)

Shear Plate Shear Plate

Bearing load acting on shear plate is presented on Figure 17.

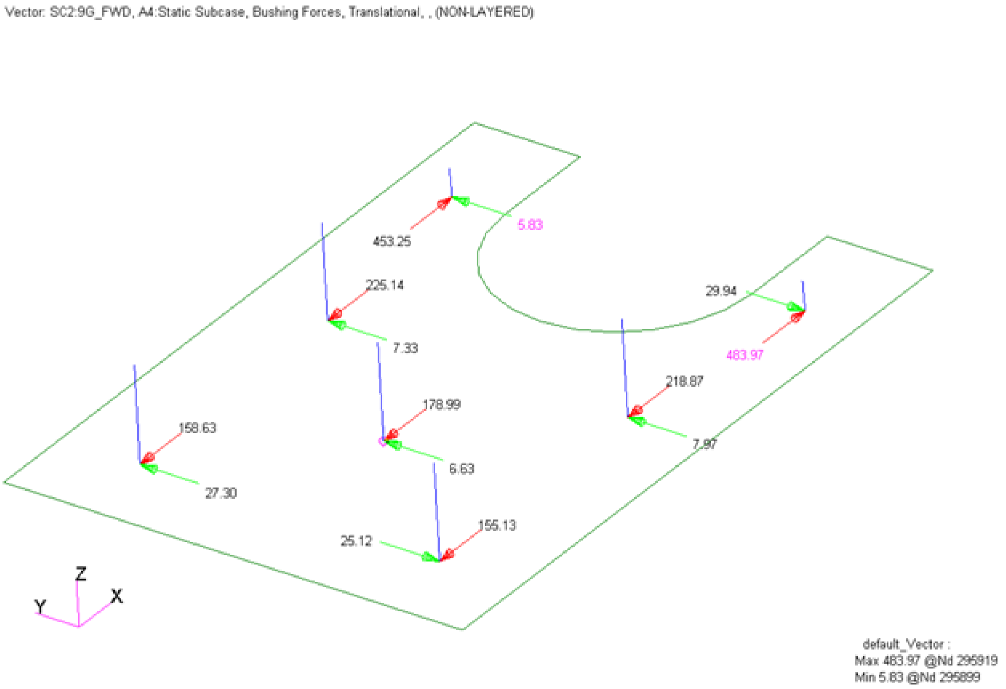


Figure 17 Critical Shear Plate (LHS AFT) Bearing Load

Critical Bearing Load Acting on LHS Aft Shear Plate

Pbr = $(483.97^2+29.94^2)^{0.5}$ = 484.89 lb (9G Forward per Figure 17)

Hole Diameter:

D = 0.13 in

Plate thickness:

t =0.063 in

Bearing allowable

Pbru =Fbru·D·t = 94000·0.13·0.063 = 770 lb

Margin of Safety with 1.33 tear and wear factor:

MS = Pbru/ (1.33·Pbr) -1 = 770 / (1.33·484.89) - 1 = 0.19 (9G Forward Load Case)

Rail

Rails Rail are used to transfer the loads from Closet to Tie-Rod Support Bracket.

Since upper rail mesh is fine grid (0.1"x 0.1"), two rows of elements are removed at each side in close proximity to the bushes modeling attachments to avoid artificial local pick stresses (the area of each removed zone is approximately 0.4"x0.4"). Von Mises stresses resulted from this analysis without omitting peak stresses and omitting them presented below. The Rail is extruded profile made of 7075-T73511 Aluminum.

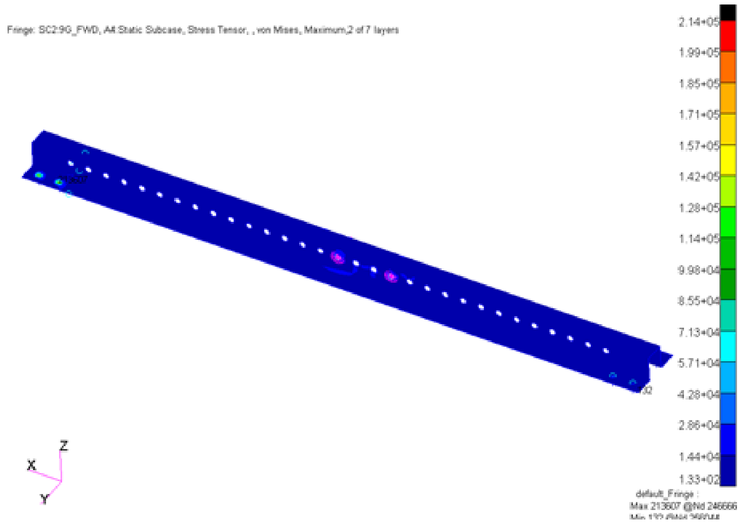


Figure 18 Von Mises Stresses in Rail Without (No Elements Omitted)

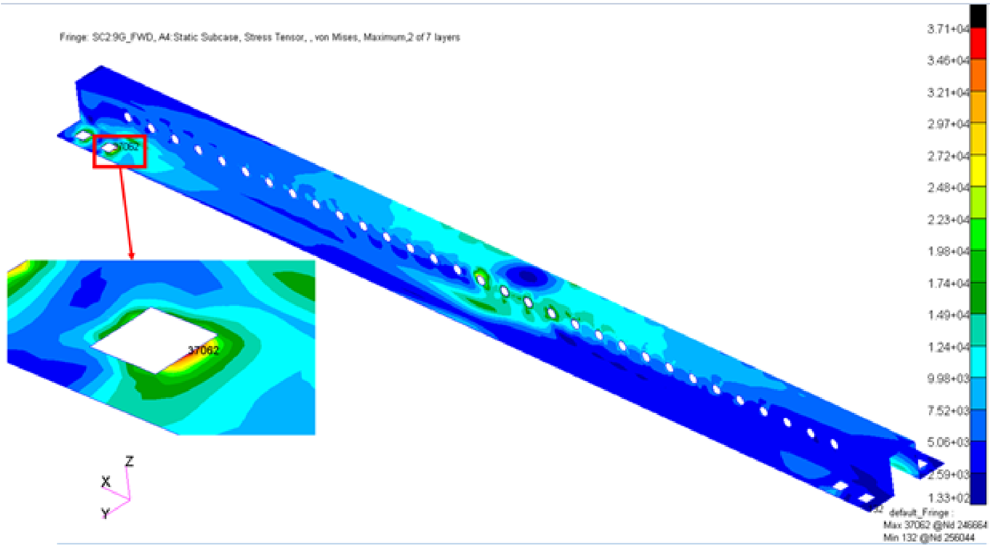


Figure 19 Von Mises Stresses in Rail Without (0.4"x0.4" Area Omitted at Each Fastener)

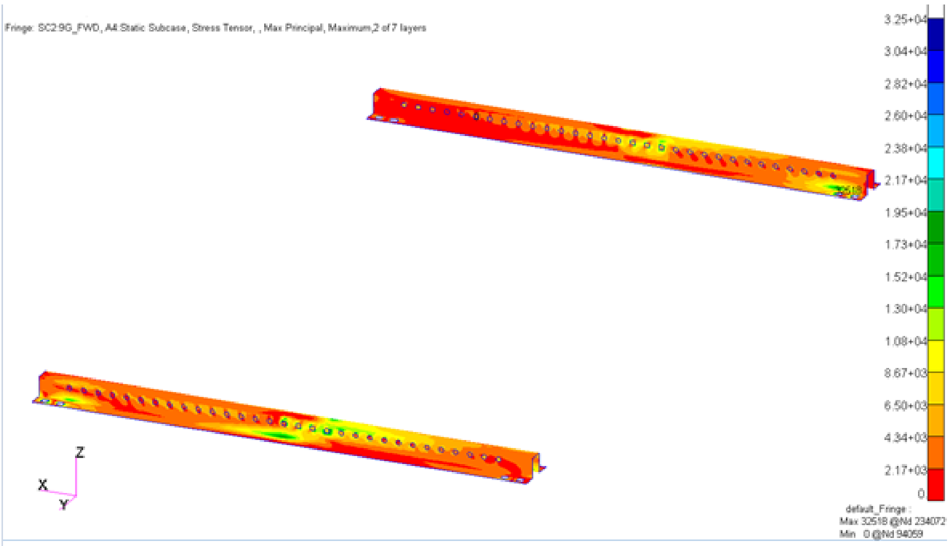


Figure 20 Rails Maximum Principal Stress Peaks Omitted

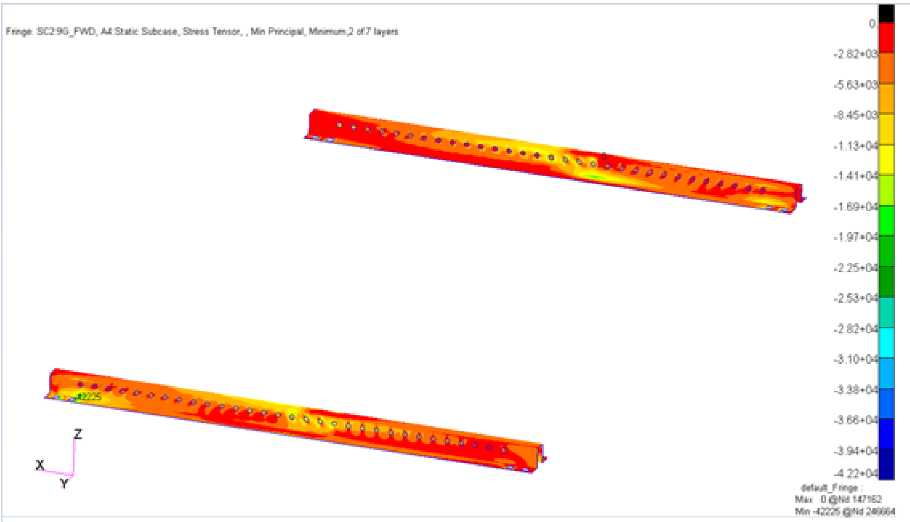


Figure 21 Rails Minimum Principal Stress Peaks Omitted

Maximum acting von Mises stress: f_vonMises = 37062 psi (see **Figure 19**)

Maximum Principal stress: f_max = 32518 psi (see **Figure 20**)

Minimum Principal stress: f_min = -42225 psi (see **Figure 21**)

Allowable stress:

FtuLT = 66000 psi

FcyLT = 56000 psi

Crippling was estimated and found to be non-critical compared to Fcy.

Therefore, Margin of Safety with 1.15 factor:

MS_comp = Fc / (1.15·ABS(f_min)) – 1 = 56000 / (1.15·42225) – 1 = 0.15 (9G Forward Case)

MS_tens = FtuLT/(1.15·MAX(f_vonMises, f_max)) – 1 = 66000 / (1.15·37062) – 1 = 0.54 (9G Forward Case)

Bearing

Additionally, bearing of Rail on Flange and Web area are analyzed. Loads Acting at Flange are shown on **Figure 22**. Load acting at Web is shown on **Figure 23**.

Flange Bearing

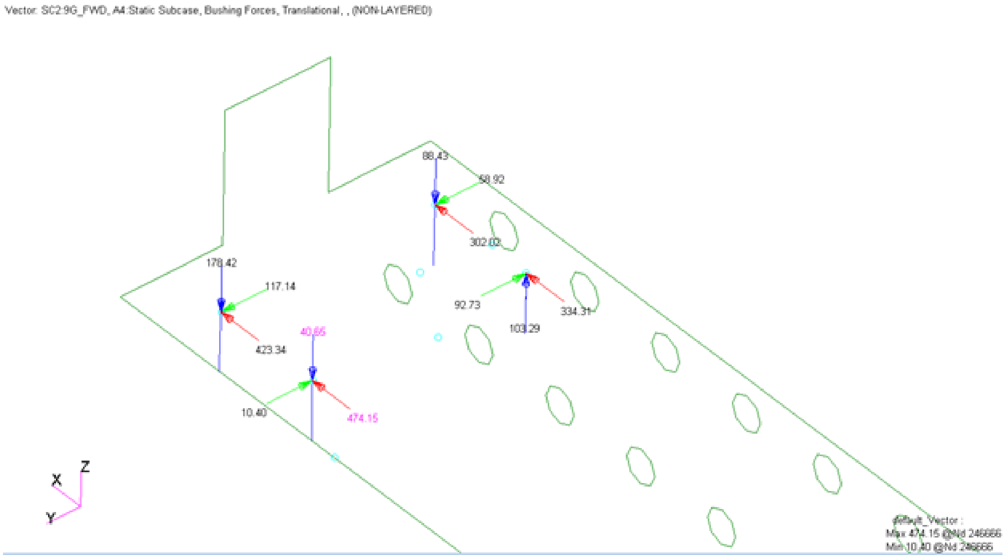


Figure 22 Rail Flange Bearing Load (9G Forward Load Case)

Allowable bearing stress:

Fbru20 = 133000 psi (see **Table**)

Rail flange thickness:

t = 0.15 in

Bolt Diameter:

d = 0.19 in (BOLT-3)

Maximal bearing Load:

$$Pb = \sqrt{Px^2 + Py^2} = \sqrt{474.15^2 + 10.40^2} = 474.26 \text{ lb}$$ (see **Figure 22**)

Bearing stress:

f_b = Pb / (d·t) = 474.26 / (0.15·0.19) = 16640 psi

Margin of Safety with 1.15 factor:

MS_bearing= Fbru / (1.15·f_b) – 1 = 133000 / (1.15·16640) – 1 = 5.95 = High (9G Forward Load case)

Web Bearing

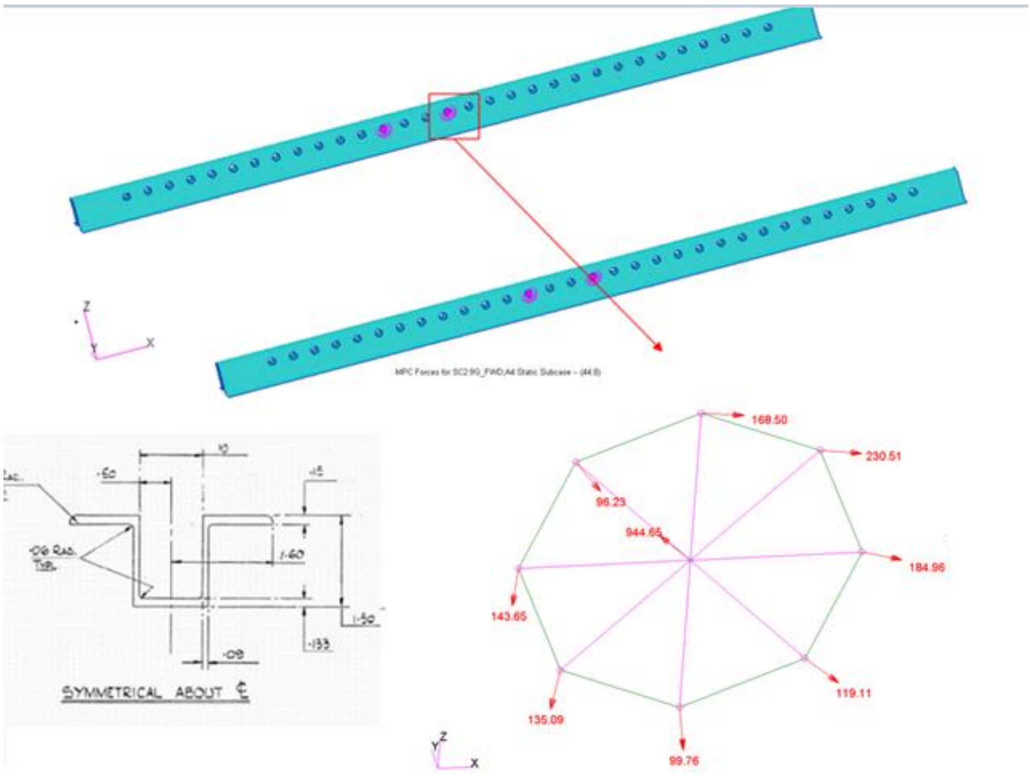


Figure 23 Rail Bearing Loads at Web (9G Forward Load Case)

Allowable bearing stress:

Fbru20 = 133000 psi (see **Table** 2)

Rail web thickness:

t = 0.09 in

Bolt Diameter:

d = 0.3125 in

Maximal bearing Load:

Pb = 944.65 lb

Bearing stress:

$$f\_b = Pb / (d \cdot t) = 944.65 / (0.09 \cdot 0.3125) = 33587 \text{ psi}$$

Margin of Safety for bearing at web:

MS_bearing= Fbru / (1.15·f_b) – 1 = 133000 / (1.15·33587) – 1 = 2.44 = High

Support Bracket Upper

Support Bracket Upper are used to attach Closet to Tie-Rods.

Bracket Pare made of 7050-T7451 Plate. The material allowables are presented below:

Ftu = 76000 psi

Fty = 66000 psi

Fsu = 44000 psi

Fbru = 101000 psi for e/D = 1.5

To evaluate Bracket strength peak stresses on the edges of holes were omitted. Figure 24 below shows von Mises stresses without and Figure 25 with omitted elements.

Figure 24 Von Mises Stresses on Support Brackets Without Omitting Peaks

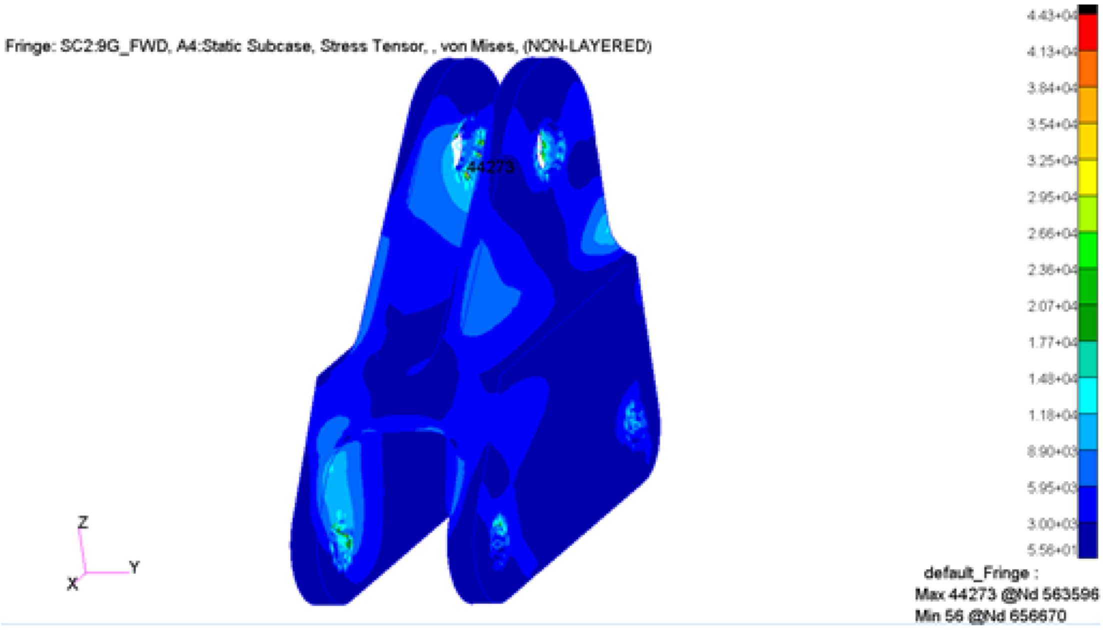


Figure 25 Von Mises Stresses on Support Brackets Omitting Peaks

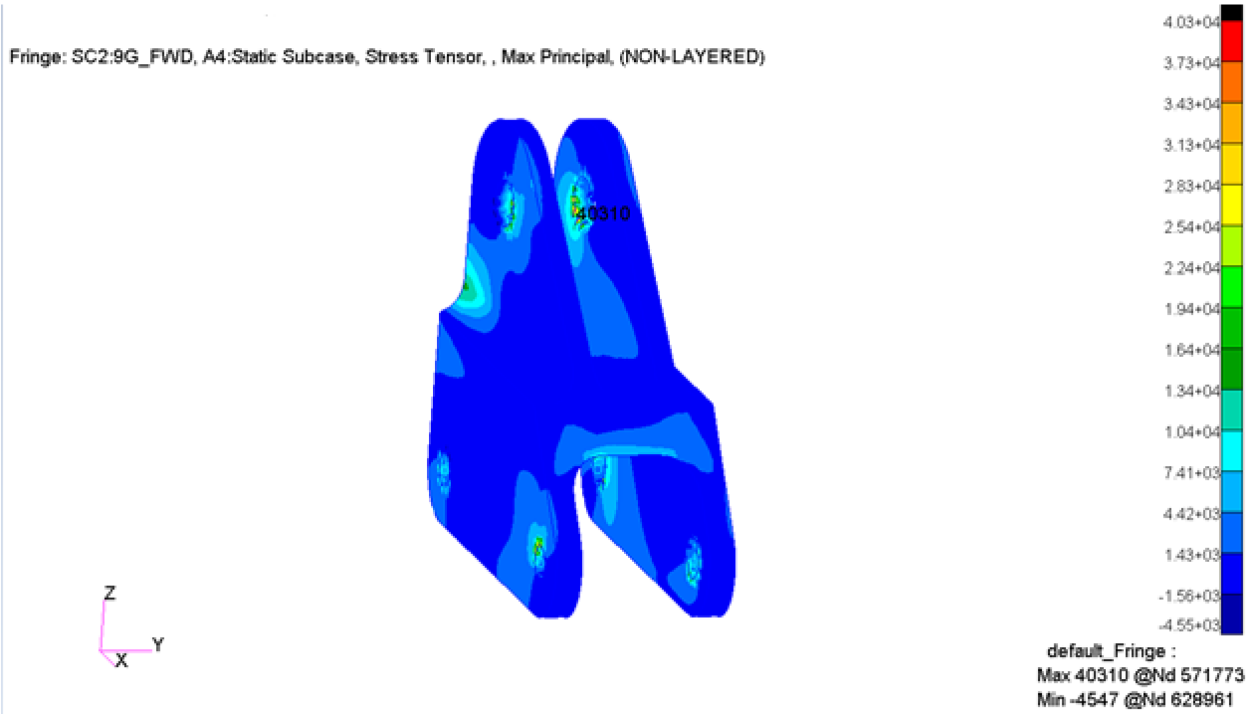


Figure 26 Maximum Principal Stresses on Support Bracket Omitting Peaks

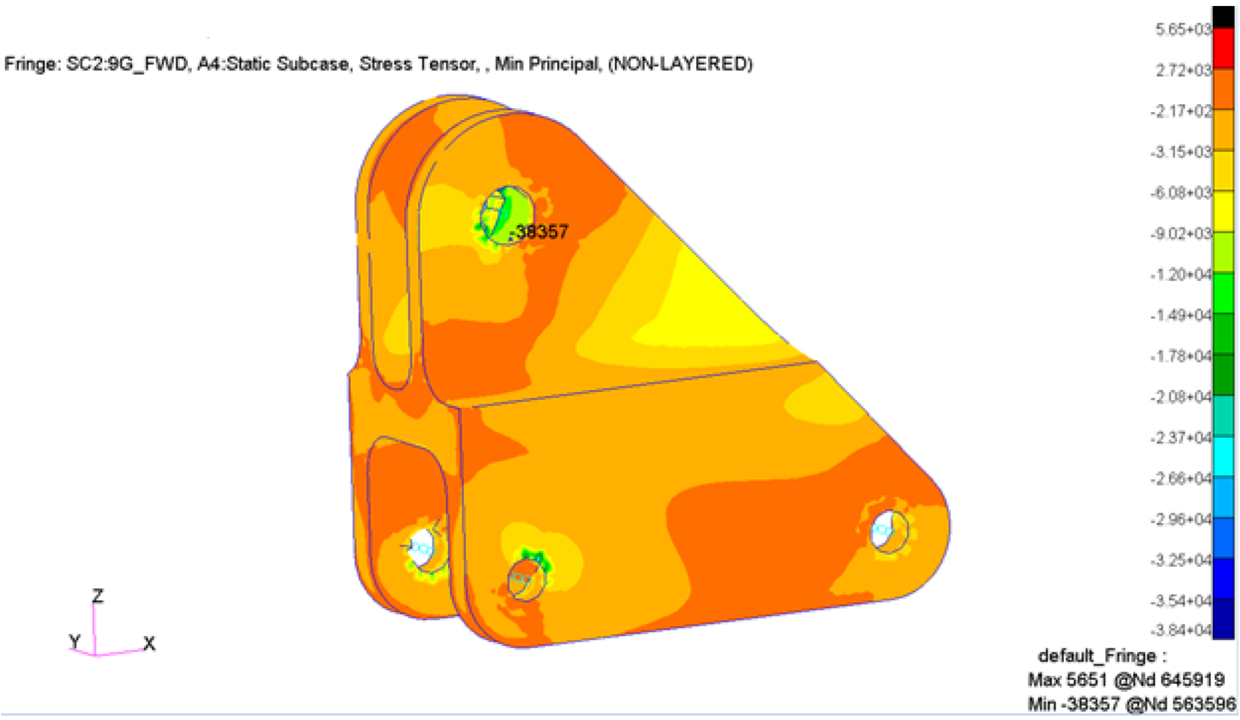


Figure 27 Minimum Principal Stresses on Support Bracket Omitting Peaks

Maximum von Mises stress: f_vonMises = 44273 psi (see **Figure 25**)

Maximum Principal stress: f_max = 40310 psi (see **Figure 26**)

Minimum Principal stress: f_min = -38357 psi (see **Figure 27**)

Margin of Safety with 1.33 wear factor:

MS_tens = Ftu / (1.33·MAX (ft_vonMises, f_max)) - 1= 76000/ (1.33·44273) - 1= 0.29 (9G Forward)

MS_comp = Fcy / (1.33·ABS(f_min)) - 1= 64000/ (1.33·38357) - 1= 0.25 (9G Forward)

Bottom holes

Bearing Load:

Pbr = 944.65 lb (see **Figure 23**)

Hole Diameter:

D=0.32 in

Leg thickness:

t=0.245 in

Bearing allowable:

Pbru =Fbru·D·t = 101000·0.245·0.32= 7918.4 lb

Margin of safety with 1.33 factor:

MS = Pbru / (1.33·Pbr) -1 = 7918.4 / (1.33·944.65) -1 = 5.30 = High (9G Forward Load Case)

Upper holes

Bearing Load

Pbr = 1798/2 = 899 lb (see **Figure 28**)

Lug Diameter:

D = 0.4375 in

Thickness:

t= 0.1875 in

Bearing allowable

Pbru =Fbru·D·t = 101000·0.4375·0.1875= 8285 lb

Margin of Safety with 1.33 wear Factor:

MS = Pbru / (1.33·Pbr) -1 = 8285 / (1.33·899) - 1 = 5.92 = High (9G Forward Load Case)

Tie-Rod

To estimate Tie-Rod Strength acting loads are compared to Tie-Rod minimal required loads. Acting Loads on Tie-Rods under Critical 9G Forward Load Case are presented on Figure 28.

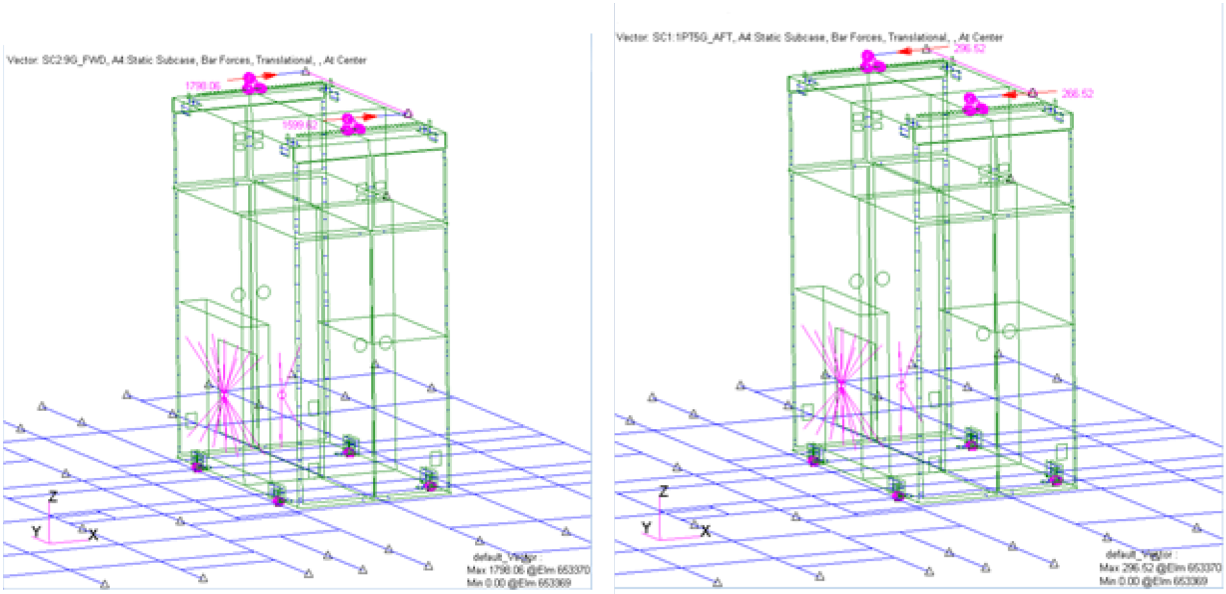


Figure 28 Maximal Tie-Rod Tension (Right) and Compression (Left)

Allowables of the Tie Rod are as follows.

Compression: P_{cu} = 2600 lb

Tension: P_{tu} = 2500 lb

Actual Loads of tie rod:

P_c =297 lb 1.5G Aft Load case

P_t =1798 lb 9G Forward Load Case

Margin of Safety for Tie-Rod Compression:

$MS = P_{cu} / (1.15 \cdot P_c) - 1 = 2600 / (1.15 \cdot 297) - 1 = 6.61$ (1.5G Aft Load Case)

Margin of Safety for Tie-Rod Tension:

$MS = P_{tu} / (1.15 \cdot P_t) - 1 = 2500 / (1.15 \cdot 1798) - 1 = 0.20$ (9G Forward Load case)

Tie-Rod Bolt BOLT-7

Bolts BOLT-7 are used to attach fitting to the tie rod.

Bolt Bending analysis is performed per.

Allowable load for inner lug is conservatively assumed to be equal to Tie-Rod minimal required tension load:

PallowO = Ptu = 2500 lb

Allowable load for outer lug is calculated using standard SCW Lug analysis procedure as shown.

PallowE= Ptru = 6806 lb

Thickness of tie-rod lug:

to = 0.325 in

Thickness of fitting lug:

te = 0.1875 in

Wo=PallowO / to = 2500 / 0.325 = 7692 lb/in

We= PallowE / te = 6806 / 0.1875 = 36299 lb/in

Using 1/W = 1/Wo+1/We, found W =6347 lb/in

Bolt diameter and moment of inertia:

D =0.3125 inch

I =0.000468 in^4

Bolt bending allowable:

M = Ftu·I / R = 160000· 0.000459 /0.156 = 479.37 in-lb

Gap:

g= 0.1275 is found from Catia model

Allowable Load:

P all=2W·((g^2+2·M/ W)$^{0.5}$-g) = 2·6347·((0.1275^2+2· 479.37 /6347)$^{0.5}$-0.1275) =3573 lb

Tie Rod Load:

Pt =1798 lb

Margin of Safety with 1.33 wear factor:

MS =Pall/ (1.33·Pt) = 3573/1.33/1798 - 1= 0.49 (9G Forward with misalignment Case)

Bolt Shear:

Ps = Pt/2 = 1798/2 = 899 psi

Shear allowable force:

Psu = 7250 lb

Margin of Safety with wear factor of 1.33:

$$MS = Psu / (1.33 \cdot Ps) - 1 = 7250 / (1.33 \cdot 899) - 1 = 5.06 = \text{High}$$

MARGINS OF SAFETY

Table 25: Critical Margins of Safety

Part Name	***Failure Mode***	***Load Case***	***MS***
Panel Assy - Divider (Core)	Combined	9G Forward	**0.32**
Divider (Facesheet)	Combined	9G Forward	**0.27**
Face Panel – Aft (Bonded Core Splice Core)	Combined	9G Forward	0.61
Face Panel – Forward (Bonded Core Splice Core)	Combined	9G Forward	High
Main Door Latch	Shear	3G Right	High
Upper Door Latch	Shear	3G Side	1.00
Dogbone	Combined	9G Forward	High
Dogbone	Combined	9G Forward	High
Dogbone	Combined	9G Forward	High
Insert (FWD Face Panel)	Combined	9G Forward	High
Insert (Floor Panel)	Combined	9G Forward	**0.10**
Insert (Ceiling Panel)	Combined	9G Forward	**0.13**
Angle Bracket	Von Mises	9G	High

		Forward	
Floor Fitting	Von Mises	3G Right	0.83
Shear Plate	Bearing	9G Forward	0.19
Rail	Compression	9G Forward	0.15
	Bearing	9G Forward	High
Bolt and Nut	Combined	9G Forward	High
Support Bracket	Tension	9G Forward	0.29
	Compression	9G Forward	0.25
	Bearing	9G Forward	High
Tie-Rod	Tension	9G Forward	**0.20**
	Compression	1.5G Aft	High
Tie Rod Bolt	Bending	9G Forward	0.49
	Shear	9G Forward	High

Margins ≥1.00 are marked as HIGH

4. Development startup project

The section analyzes the marketing analysis of a startup project, as well as identifies opportunities and feasibility of its introduction to the market.

The content of the project idea

Table 26 Description of the idea of a startup project

The content of the idea	Areas of application	Benefits for the user
Increasing the allowable flight cycles of the closet with damage on the panel	For production needs	It is possible to cover the closet inspect less frequently, which will reduce the time for technical inspection of equipment
	For airlines	Permissible damage become more, which will reduce the number repairs on the panel of the closet

The dependence offered by the author allows to define the factor for reduction of quantity of cycles to destruction of a plate with an aperture in quantity of cycles to destruction of a panel with a damage that reduces time for calculation of durability of a covering of a panel.

Table 27 Identification of strong, weak and neutral characteristics of the project idea

№	Technical and economic characteristics of the idea	Project idea
1	Save time	S
2	Improving reliability	N
3	The complexity of the calculation	N
4	Financial savings	S
5	Information support	W

This table shows that the competitiveness of the idea is high.

Technological audit

You can implement the project idea with the help of project calculations.

Table 28 Technological feasibility of the project idea

№	Project idea	The path of implementation	Availability of technology	Availability of technology
1	Creation of design documentation necessary for accurate and high-quality manufacturing of a part	Creating design documentation	available	available
2	Use of premises and specialized equipment for the manufacture of aircraft structures	Manufacturing at the enterprise	available	available
The path of implementation and opportunities are available				

Analysis of market opportunities to start a startup project

Identifying market opportunities that can be used during the market implementation of the project, and market threats that may hinder the project, are quite difficult given that different methods of solving this problem are part of long-term scientific development of the industry. That is, it is possible to assess the potential market of a startup project only in the long run, without based on clear numerical characteristics of the market.

In terms of researching the idea of the project, the potential market can be considered various airlines of passenger aircraft and aircraft manufacturers that are interested in finding a reduction in the number of technical inspections of aircraft and design improvements.

Table 29 Preliminary description of the potential market of a startup project

№	Market indicators	Characteristic
1	Number of main players, units	10
2	Total sales, UAH / unit	56000
3	Market dynamics (qualitative assessment)	is growing
4	There are restrictions for entry	no
5	Specific requirements for standardization and certification	aviation rules
6	Average rate of return in the industry (or market),%	73%

Potential customer groups can be divided into primary and secondary consumers of the product. The primary group is companies producing fuselage plating, the secondary - airlines that buy aircraft. An indicative list of product requirements for each group is given in Table 4-5.

Table 30 Characteristics of potential clients of the startup project

<table>
<tr><th>The need that shapes the market</th><th>Target audience</th><th>Differences</th><th>Consumer requirements for the product</th></tr>
<tr><td>Profit</td><td>Manufacturers</td><td rowspan="3">Behavior is dictated by the market situation, the popularity of the product among different groups of buyers, the payback of the product</td><td>Construction efficiency and weight</td></tr>
<tr><td>Saving money</td><td>enterprises-buyers</td><td>Maintainability</td></tr>
<tr><td>Saving money</td><td>Airlines</td><td>Value for money</td></tr>
</table>

In order to conduct an in-depth analysis of the market environment, tables of factors that contribute to the market implementation of the project and the factors that hinder it are compiled. The above threats and opportunities are listed below in Tables 31 and 32.

Table 31 Threat factors

№	Factor	The content of the threat	Reaction of companies / scientists
1	Scientific	Achieving scientific and technological progress, development of new technologies	Constant development of the idea, constant improvement of the existing method, search of radically new and better methods
2	Technical	Dramatic changes in the market of hardware software	Constant monitoring of the situation in this market
3	Financial	At deterioration of macroeconomic conditions the firm - the manufacturer of coverings of a fuselage can make the decision to save at the expense of reduction of expenses for scientific department.	Allocation of sustainable funding, which is not subject to external financial factors with a full understanding of the fact that in the development of science department lies the future prospects of the industry
4	Political	The political situation in the country or in a particular economic region	Backup databases, archiving information from research, monitoring the political situation.

Table 32 Opportunity factors

№	Factor	Content of the opportunity	Possible reaction companies
1	Increasing demand for old aircraft	Increasing demand for product improvements, and as a consequence, for new improvements approaches to calculation	Increasing the company's profits will push to increase the number closet
2	The emergenc e of a new aircraft	Positive impact from the point of view improvement and implementation of this design.	More often and more effectively use of this design
3	Using c other areas	Further study of this constructions for improvement	Expansion product range

Table 33 Step analysis of competition in the market

Features of the competitive environment	What is this characteristic	Impact on business activities
Type of competition : pure	There are no restrictions on the market for new entrants	Constant monitoring of the situation in this market, maintaining competitiveness
Local level of competition	The market is represented point by point in different states in varying degrees of concentration	Dynamic market development will take place only in case of joint work of its participants.
Intra-industry competition	Competition in the market takes place between representatives of one industry production or one area of research	Constant analysis of trends, the policy of constant competition
Commodity competition by type of product	Competition between different configurations	The research department is under constant threat of new developments
Vintage intensity	Competitors are companies with a similar product	Conducting activities in conditions constant competition

After the analysis of competition we carry out more detailed analysis of conditions of competition in branch (tab. 34).

Table 34 Analysis of competition in the industry

Components of the analysis	Direct competitors in the industry	Potential competitors	Customers	Substitute goods
	None	There are no barriers to implementation	Boeing, Airbus	There are threats from substitutes
Conclusion and:	Low intensity	There is an opportunity to enter the industry	Dictate working conditions in the market. Such as time to calculate and provide the necessary software	No restrictions on substitutes

Given the competitive situation, it is possible to enter the market of this industry. To be competitive in the market of this project it is necessary to develop software for high-speed calculation of the methodology.

Table 35 Substantiation of competitiveness factors

№ p / p	Competitiveness factor	Rationale (citing factors that make the factor for comparing competing projects significant)
1	Accuracy of calculations	Improving the results
2	Use of the received data	Maximum resource depletion

According to certain factors of competitiveness (table 35) we will analyze the strengths and weaknesses of my startup project (Table 36).

Table 36 Comparative analysis of strengths and weaknesses "Coefficient to reduce the number of cycles to the destruction of the panel in the number of cycles to the destruction of the panel with the damage"

№ p / p	Competitiveness factor	Bali 1-20	Rating of the method in comparison with the competitor's project						
			-3	-2	-1	0	1	2	3
1	Less cost requirements	20					●		
2	Accuracy of calculations	20				●			
3	Use of the received data	20					●		
4	Accuracy of calculation in the project	15					●		

The final stage of the market analysis of project implementation opportunities is the compilation of SWOT-analysis (matrix of analysis of strengths (Strength) and weaknesses (Weak) sides, threats (Troubles) and opportunities (Tables 37) on the basis of selected market threats and opportunities, and strengths and weaknesses (table 36).

The list of market threats and market opportunities is based on the analysis of threats and factors of the marketing environment. Market threats and market opportunities are the result of the influence of factors, and, in contrast, are not yet realized in the market and have a certain probability of implementation.

Table 37 SWOT analysis of a startup project

Strengths: Safe depletion of resource elements	Weak sides: complexity software support methodology
Opportunities: conquest the whole industry	Threats: development more precisely methods

Based on the SWOT analysis, alternatives of market behavior are developed to bring a startup project to market and the approximate optimal time of their market implementation, taking into account potential projects of competitors that may be brought to market.

The development of a market strategy as a first step involves determining the strategy of market coverage: a description of the target groups of potential consumers (Table 38).

Table 38 Selection of target groups of potential consumers

№ p / p	Description of the profile of the target group of potential customers	Readiness of consumers to accept the product	Estimated demand within the target group	Intensity of competition in the segment	Easy to enter the segment
1	Boeing, Airbus	Completely ready	High	Average	Simply

To work in the selected market segment, it is necessary to form a basic development strategy (Table 39).

Table 39 Definition of the basic development strategy

An alternative project development is selected	Market coverage strategy	Key competitive positions according to the chosen alternative	Basic develop ment strategy
Alternative	Coverage by 77-83%	Conc.1 and Conc2	Specialization

Next, choose a strategy of competitive behavior (table 40).

Table 40 Defining the basic strategy of competitive behavior

Is there a project A "pioneer" in the market?	Will the company look for new customers, or take away existing ones from competitors?	Will the company copy the main characteristics of the competitor's product, and which ones?	Strategy of competitive behavior
No	So	Copy only commonly used ideas	Industry occupation strategy

The result of this unit is an agreed system of decisions on the market behavior of the startup company, which will determine the directions of the startup company in the market:

– use of modern technologies in the project;

– direction of work only in a given market niche.

The first step is to form a marketing concept of the product that the consumer will receive. To do this, in table 41 summarize the results of a preliminary analysis of the competitiveness of the product.

Table 41. Identify the key benefits of the concept of a potential product

№ p / p	Need	The benefits offered by the product	Key advantages over competitors
2	Increased demand in the field of aircraft construction	Reducing the number of repairs	Reduction of calculation costs

The last component of the marketing program is the development of the concept of marketing communications, based on a pre-selected basis for positioning, defined specifics of customer behavior (Table 40).

Table 42 The concept of marketing communications

The specifics of the behavior of target customers	Communication channels used by target customers	Key positions selected for positioning I	The task of the advertising message	The concept of advertising appeal
Communic ation	Internet, scientific works	Advertising methods for the conference x	Expansion of target customers	Show that our technique is better and more appropriate

- market demand is now and will develop
  - High competitiveness
  - uniqueness of the idea
  - there are no restrictions on entering the market

Conclusions

a. The finite element model was created allows to investigate the strength of composite structures closet interior passenger plane.

b. The created FEM model allowed to determine the coefficients of safety of all individual structural elements of the cabinet and its fastening elements to the floor and ceiling of the cabin of the aircraft under loads that may occur in critical situations.

c. All elements of a case design have a sufficient safety margin, their coefficients of a safety margin are in the range from 0.1 to 5

d. Elements of fastening of a closet to a floor and a ceiling of cabin of the plane need strengthening as their coefficients of a safety margin do not exceed 0.2.

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